Key enabling technologies for Europe's technological sovereignty

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Key enabling technologies for Europe's technological sovereignty

Technological sovereignty has been at the heart of recent political debate in the EU. Interest has only been strengthened by the Covid-19 pandemic crisis, due to its impact on many value chains.

Key enabling technologies (KETs) – advanced manufacturing and materials, life-science technologies, micro/nano-electronics and photonics, artificial intelligence, and security and connectivity technologies – are crucial for an interconnected, digitalised, resilient and healthier European society, as well as being important for the EU's competitiveness and position in the global economy.

This STOA study analyses how the EU is performing in developing and protecting ownership and know-how in these critical technologies, especially in comparison with strong global players such as China and the United States of America. Based on the challenges identified in the analysis, it discusses policy options for strengthening the EU's technological sovereignty in KETs.

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Executive summary

Europe's journey towards technological sovereignty

Technological sovereignty has been at the heart of political debate in Europe. Interest has only been strengthened by the Covid-19 pandemic, due to its impact on many value chains. Interpretations of technological sovereignty in the EU differ. They call for stronger European independence by promoting the creation of European champions, or by protecting European companies against foreign players. The definition of technological sovereignty devised for this study aims to reconcile these two approaches in Europe's ability to develop, provide, protect and retain the critical technologies required for the welfare of European citizens and prosperity of European businesses, and the ability to act and decide independently in a globalised environment.

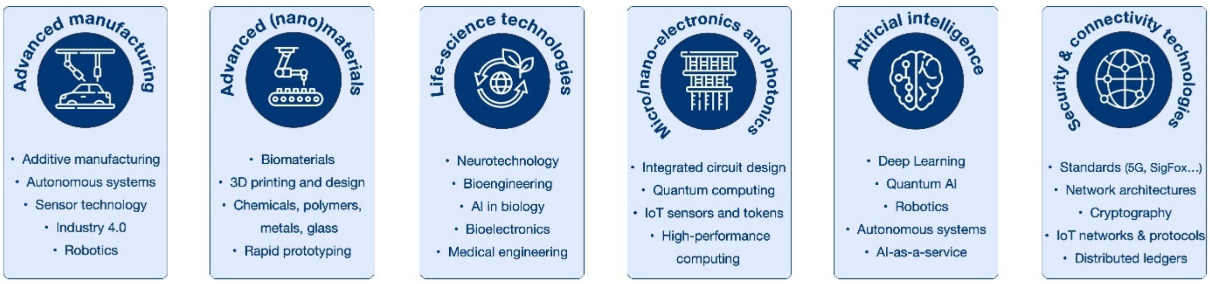
This definition encompasses three key elements:

- **Technological** – the development of European research and development (R&D) competencies by maintaining a strong knowledge base, industry, and networks in the critical technologies;
- **Economic** – the achievement and preservation of a position of leadership in key enabling technologies (KETs), the ability to turn R&D into market products, and access to a diversity of resources along the value chain with the aim of reducing dependence on third countries;
- **Regulatory** – the development of adequate policies and standards that reflect European values, to influence global regulation, standards and practices.

The importance of KETs for Europe's technological sovereignty

The six KETs identified as critical for Europe to reach technological sovereignty are presented in the figure below. Advances in these KETs contribute to an interconnected, digitalised, resilient and healthier European society, are important for the EU's competitiveness and its position in the global economy. To make use of the full potential of the KETs, the transformation of society through technology needs to consider the key impacts affecting jobs and the environment further described in this study.

Six KETs and their major applications



Analysis of the KETs led to identification of key requirements for their development, essential to ensuring Europe's ability to master these technologies. Four important challenges were identified for the six KETs.

- **Lack of resources/raw materials**: Europe is dependent on third countries for access to many of the critical raw materials or resources needed in the context of KETs. Quality datasets, which as a fundamental enabler for artificial intelligence (AI) can also be considered a resource, are not available to the vast majority of European companies.

- **Dependence on non-European suppliers**: In several KETs (i.e. micro/nano electronics and photonics, and life-science technologies), many of the supply and value chains depend on non-European companies and know-how that put Europe in a position of dependency in the global geo-political context.
- **Digital skills**: A lack of and drain on technological expertise can be observed, which compromises European industry and academia. In a more digitalised and connected society, the acquisition of specialised digital and technical skills for both workers and end users are essential to realise the full potential of KETs.
- **Commercialisation of research results**: Europe struggles to turn the outputs of scientific research results into commercial products and retain them in Europe. The majority of currently successful business models and products originate in non-European companies.

In a more general assessment of EU policies, regulatory fragmentation has been identified as a fifth challenge, i.e. the **lack of joint action and coordination** between different levels of governance, and sometimes different policies.

Technological sovereignty assessment

First, the study identifies key 'ingredients', i.e. elements that are critical to reach technological sovereignty with regard to KETs-related research and industry. These are ingredients, because several elements need to be combined to reach the technological sovereignty objective, e.g. industry leadership will not be reached without research and vice versa. The ingredients are related to the proposed definition of technological sovereignty, and translate into actions as follows:

- Develop: the capacity to develop R&D competencies and knowledge thanks to the support of public and private sectors, discussed under the ingredient of R&D and innovation (R&D&I) funding;
- Provide: the capacity to turn R&D into market products and a reduction in dependence on third countries, by building the right industrial ecosystem through the creation of start-ups and the leadership in critical technologies;
- Protect: the capacity to achieve and preserve technological leadership, by favouring the delivery of innovation through patenting and co-inventions;
- Retain: the capacity to maintain competencies and knowledge through adapted education and skills to ensure the availability of the necessary qualified people in research and production of critical technologies.

In the next step, indicators were associated with each of the ingredients and then assessed in terms of their relevance for technological sovereignty. The study selected indicators to reflect EU performance with respect to the definition of technological sovereignty and consequently to determine Europe's position with regard to third countries. The availability of the data was another important consideration in the final selection of indicators.

Europe losing ground in technologies despite strong commitments

The analysis shows that Europe has many good intentions and has made strong efforts to support the development of KETs, which are highlighted by dedicated investment programmes, research successes resulting in patents, and a competitive start-up ecosystem. However, when it comes to the six KETs and Europe's technological sovereignty, the results also show that Europe lags behind China and the United States of America (USA), due to a lack of R&D funding, especially from the private sector; a lack of qualified skills in technology; and a lack of industrial leaders in KETs. Ultimately, Europe loses ground, with its many good ideas and companies being acquired by non-European players.

Policy options

The policy options set out in this study are organised into four packages. The four packages follow the definition of technological sovereignty and its three key elements: technological, economic and regulatory. The first package outlines a proposal for a new EU strategy for KETs based on an institutionalised policy dialogue between all the relevant players: EU institutions, Member States, regions, academic and industry stakeholders, including small and medium-sized enterprises (SMEs). The other three packages address the four key challenges across the KETs. They are, however, not KETs-specific, and should therefore contribute to improving the access to raw materials, reducing dependence on non-European suppliers, advancing skills and commercialisation generally. The study suggests a total of 25 options to reach the common goal of achieving Europe's technological sovereignty. Most policy options target EU policy-makers, but some could be taken up at national level.

Specifically, the first package presents measures related to two more general policy options, which are formulated based on discussions with stakeholders. Their objective is to help overcome the harmful competition between Member States, while providing the basis for joint effort, a space for mutual learning and developing common ideas, exchanging best practices and helping overcome administrative inertia. First, a **more coordinated and inclusive approach is necessary for different policy areas and instruments,** such as a forum for continuous policy dialogue with Member States and stakeholders. Secondly, policy-making should be evidence-based: **indicators to measure regulatory impacts and monitoring and evaluation frameworks for all KETs** should be introduced and used to better respond to issues.

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Abbreviation	Meaning
AI	Artificial intelligence
ARWU	Academic Ranking of World Universities (Shanghai Ranking)
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrotechnical Standardisation
DARPA	Defense Advanced Research Projects Agency
DEP	Digital Europe programme
DL	Deep learning
DIHs	Digital innovation hubs
DoD	United States Department of Defense
ECB	European Central Bank
ECRA	Export Control Reform Act
EIB	European Investment Bank
EIC	European Innovation Council
EIT	European Institute of Innovation and Technology
EPO	European Patent Office
EPRS	European Parliamentary Research Service
ERA	European research area
ESIF	European Structural and Investment Funds
ETSI	European Telecommunications Standards Institute
EUV	Extreme ultraviolet lithography
FDI	Foreign direct investment
FIRRMA	Foreign Investment Risk Review Modernization Act
GAFAM	Google, Apple, Facebook, Amazon, Microsoft
GDPR	General Data Protection Regulation
HLG	High Level Group
HPC	High performance computing
ICT	Information and communication technologies
I-DESI	International Digital Economy and Society Index
IoT	Internet of things
IPCEI	Important projects of common European interest
IT	Information technology
IPR	Intellectual property rights
JP¥	Japanese Yen
JRC	Joint Research Centre

KETs	Key enabling technologies
ML	Machine learning
NMBP	Nanotechnologies, advanced materials, advanced manufacturing and processing, and biotechnology
PPP	Private-public partnership
QC	Quantum computing
R&D&I	Research & development & innovation
RTO	Research and technology organisation
SMEs	Small and medium-sized enterprises
STEM	Science, technology, engineering, and mathematics
TRL	Technology readiness levels
UAV	Unmanned aerial vehicle
USA	United States of America
USD	United States Dollar
WEF	World Economic Forum

1. Introduction

1.1. Foreword

The **six KETs presented in this study were defined by the High Level Group (HLG) on industrial technologies** in its report **'Re-Finding Industry Defining Innovation',** published in 2018.[1] Its preface already addressed a distinct situation in Europe, with its strengths and potentials on the one hand, and its weaknesses and its, at times, misguided approach, on the other. As noted by Jürgen Rüttgers, Chair of the independent HLG, 'Instead of addressing these challenges, which we [Europe] can only master together, there is discord and no plan'. Facing the risk of losing against competition from third countries, especially the USA and China, the HLG drafted several targets for the future to protect and preserve Europe's values, to strengthen the industrial base, especially around start-ups and small and medium-sized enterprises (SMEs), to generate productivity and create jobs, and, above all, to act as a united Europe. The group also calls for 'the European Parliament, the European Commission and the European Council [to] be courageous and break new ground together'. In the report, the HLG also recommended a mission-oriented approach to innovation policy, also reflected in an ambitious economic and industrial policy for the development of KETs in Europe.

1.2. Scope

This study aims to support the Members and Committees of the European Parliament in understanding the key issues related to KETs and to provide the necessary information and analysis for informed decision-making.

The report is organised into four chapters. The study methodology is set out in Appendix 1.

- Chapter 1 presents a definition of the concept of technology sovereignty;
- Chapter 2 introduces the six KETs by providing a definition and describing the potential applications as well as the main challenges along the technological value chain per KET;
- Chapter 3 provides a state of play on research and industrial leadership related to the six KETs;
- Chapter 4 describes potential policy options.

1.3. A definition of technological sovereignty

By gaining important political traction, the term 'technological sovereignty' has become interchangeable with other terms such as 'strategic autonomy', 'industrial autonomy', 'industrial sovereignty', 'digital sovereignty', which describe slightly different phenomena. This chapter develops a definition of technological sovereignty for the present study based on a literature review and targeted interviews with a range of stakeholders.

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[1] 'Redefining Industry: Defining innovation', Report of the independent High Level Group on industrial technologies, Directorate General for Research and Innovation, European Commission, 2018. Page 5 (preface).

1.3.1. Political debates on the European definition of technological sovereignty

The political discussion on technological sovereignty is longstanding and stems from concerns about **losing global economic clout and geopolitical influence due to an overreliance on foreign providers** in certain key technologies.[2]

Over the past year, attention has increasingly been paid to technological sovereignty, which is now included in many national agendas. In February 2020, the European Commission unveiled its ideas and actions regarding how Europe can retain its technological and digital sovereignty and become a global leader in its Communication on Shaping Europe's digital future.[3] It further defines that **technological sovereignty starts with ensuring the integrity and resilience of our data infrastructure, networks, and communications**. For this, Europe needs the right conditions to develop and deploy its own capacities and reduce its dependency on other parts of the globe for KETs. As President of the European Commission, Ursula von der Leyen has set the objective of achieving technological sovereignty in some critical technology areas by 2024.[4] Specifically, she describes sovereignty as 'the capability that Europe must have to **make its own choices, based on its own values, respecting its own rules**'.

This concept of technological sovereignty should, however, not be understood as defined against anyone else, but instead, based on the **needs of Europeans and the European social model**. This is illustrated by the Commission in the digital area with the aim of a European society powered by digital solutions that are strongly rooted in our common values and that enrich the lives of all citizens: people must have the opportunity to develop personally, to choose freely and safely, to engage in society. Data should be available to all and will support society to gain the most from innovation and competition. This digital Europe should reflect the best of Europe – openness, fairness, diversity, democracy, and confidence.[5]

In early 2020, the **lack of resilience showcased by the Covid-19 pandemic reinvigorated debates** on technological and industrial sovereignty in Europe. The pandemic paralysed many value chains, which had been trimmed over past years to be as efficient as possible through just-in-time and lean production methods. Specifically, European Commissioner for the Internal Market, Thierry Breton recognised how the pandemic has revealed the lack of access to protective equipment, while the overreliance on a few third countries highlighted the strategic importance of some previously neglected value chains.[6]

1.3.2. Approaches to define technological sovereignty in Europe

Currently, there is no **common definition** of technological sovereignty in the EU (as well as globally). While some, including a few of our interviewees, argue that a definition is not necessary or is even counterproductive (as we should define more specific objectives), the lack of a definition causes ambiguity. This can lead to divisive rhetoric and thus threaten the EU's ambitions for technological sovereignty, since the policy objectives and the impact of the ambitions depend on the definition of the term.

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[2] Bauer M. and Erixon F. (2020) Europe's Quest for Technology Sovereignty: Opportunities and Pitfalls. In: ECIPE occasional paper.

[3] European Commission (2020) Communication: Shaping Europe's digital future.

[4] Ursula von der Leyen (18 February 2020): Tech sovereignty key for EU's future goals. In: The Irish Examiner.

[5] European Commission (2020) Communication: Shaping Europe's digital future.

[6] European Commission (September 2020) News. Europe: The Keys to Sovereignty.

Interpretations of the term 'technological sovereignty' can be divided into two groups. The first group promotes the independence of Europe technology-wise. The second group advocates the need to protect European competitiveness against foreign players.

- The **offensive approach of promoting research and industry** fits with the industrial strategy aiming at creating 'EU industrial champions' for increased autonomy and reducing dependence on third countries. In 'A New Industrial Strategy for Europe',[7] the Commission sets out the EU's ambition to master critical technologies and to support KETs, which are essential for Europe's industrial future. It calls for the reinforcement of Europe's strategic autonomy, which means 'reducing dependence on others for things we need'. However, in an open and interconnected global economy, access to technologies is crucial for many businesses and governments, so technological independence is not the final answer.[8] Nevertheless, **an economy the size of the EU has the ability to control key generic technologies and infrastructures, as well as to set global standards for these technologies in cooperation with international partners**;
- The **defensive approach aims to protect technologies and industries**. This can be seen in the digital field, with the threat of non-European players dominating critical digital sectors. The Commissioner for Competition, Margarethe Vestager, has been actively promoting Europe's technological sovereignty by opening antitrust investigations into companies such as Apple, Google and Amazon, or by calling for stronger EU regulation of digital markets (e.g. through the digital services act).[9] Similarly, Commissioner Breton, has been an advocate of protectionist policies from data localisation to fostering European digital champions.[10] However, technological sovereignty based on **outdated protectionist ideas may ultimately hurt the EU,** as it will increase the risk of exposing the EU to third country retaliatory measures and make it harder for many Member States to access crucial modern technologies.[11]

1.3.3. Suggested definition of technological sovereignty

For this study, we have developed a definition for technological sovereignty based on the literature review and conducted interviews, which tends to reconcile the two approaches explained above.

We define European technological sovereignty as **the ability for Europe to develop, provide, protect, and retain critical technologies required for the welfare of European citizens and prosperity of businesses, and the ability to act and decide independently in a globalised environment.**

This definition encompasses three key elements:

- **Technological** – the development of **European R&D competencies** by maintaining a strong knowledge base, strong industry, and strong networks in the **critical technologies**;

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7 European Commission (2020) A New Industrial Strategy for Europe, COM(2020) 102 final.

8 Leonard, M., Pisani-Ferry, J., Ribakova, E., Shapiro, J. and Wolff, G. (2019). Redefining Europe's economic sovereignty. Joint publication of Bruegel and the European Council on Foreign Relations. June 2019. Available at https://bruegel.org/wp-content/uploads/2019/06/PC-09_2019_final-1.pdf.

9 The Digital Services Act package. See: https://ec.europa.eu/digital-single-market/en/digital-services-act-package.

10 Mark Scott (27.10.2019) What's driving Europe's new aggressive stance on tech. Fears of being swallowed up by China and the US fuel push for more assertive digital policies. In: POLITICO

11 Science Business (September 2020) Decoding Europe's new fascination with 'tech sovereignty'

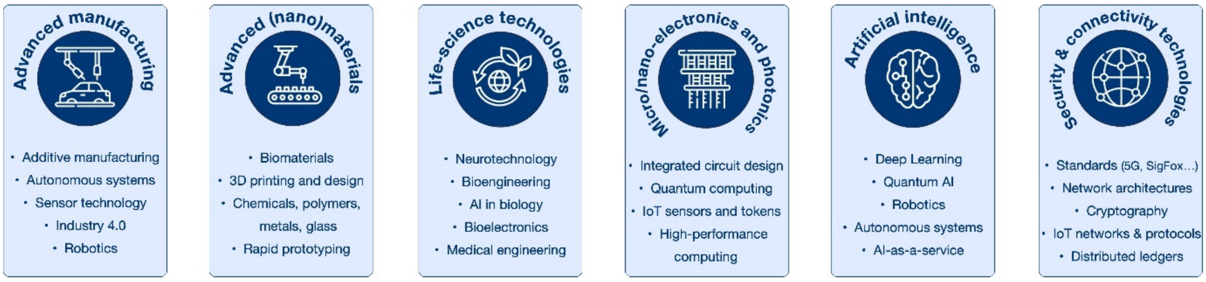
- **Economic** – the achievement and preservation of a **position of leadership in KETs**, the ability to turn R&D into market products, and having access to a diversity of resources along the value chain with the aim of **reducing dependence on third countries**;
- **Regulatory** – the development of adequate policies and standards to **influence** global regulation, standards, and practices that **reflect European values**.

2. The KETs – Perspective and development

In this chapter, we present our analysis of the six KETs, presented in Figure 2.1, that are of paramount importance for Europe's technological sovereignty in the future. For each presented KET, we provide a definition, describe its main uses and its importance and potential for Europe, with respect to technological sovereignty, and social and economic impact. In this context, we will also outline the main challenges and requirements along the technological value chain.[12] All information reflected in this chapter is based on desktop research and interviews with experts from industry and academia.

Throughout this chapter we also present five different case studies that use or build on one or more KETs.

Figure 2.1: Overview of the six KETs



Source: Authors' own work.

2.1. KETs: definitions and applications

Before diving into the definitions and applications of each KET, we want to describe some connections between the KETs on a general level. The KETs micro/nano-electronics and photonics, security and connectivity technologies, and artificial intelligence (AI) are clearly transversal, thereby building the foundation for other KETs (e.g. advanced manufacturing, life-science technologies). This can be explained as follows: micro/nano-electronics in particular, but also photonics, represent an indispensable foundation for almost all technological advancements, because in many cases they provide the minimal building units for further applications. Whenever data or information is exchanged, the security and connectivity technologies come into play, ensuring the security of such transfer. Lastly, AI is also transversal due to its applicability in so many different application domains that are not limited to the KETs.

2.1.1. Advanced manufacturing

Definition and importance

Advanced manufacturing describes the use of **innovative technologies and methodologies** in the manufacturing domains to improve existing products or create new ones. The main ambition is to **enhance the output of manufacturing** through improved and more efficient processes as well as high-performance production facilitated by digitalisation, i.e. production and manufacturing activities that build on data, computational results, automation, or sensing. Thus, advanced manufacturing and related technologies can **boost productivity** by **increasing flexibility** and

[12] By 'technological value chain' we denote the various steps required to produce, prepare and/or provide a technological product for our economies and societies. This might include for example the required raw materials, the semiconductor chips, the software programs and the skilled experts that need to operate a particular product/service.

making it viable for more and more manufacturers to offer highly customised products to customers. In addition, manufacturers can produce in smaller batches for specific customers or more easily adjust their production to design changes.

Advanced manufacturing encompasses different topics and applications, including but not limited to:

• Additive Manufacturing • Industry 4.0 concepts • Industrial-IoT • Manufacturing process optimization	• Sensor technology • Interconnectivity between factories and manufacturing sites • 5G and 6G[13] • Intelligent robotics	• Autonomous systems • UAV technology • Telecommunications • Operating systems for various nodes

Potential applications

The applications of this KET target all manufacturing processes and domains. Given the current challenges of EU Member States in terms of declining population, **increased automation in production and manufacturing could** help address labour shortages expected in the coming decades. Furthermore, processes in factories and production should be further optimised and improved to increase the competitiveness of the European economy. This KET will increase the **overall quality of products** as well as the **responsiveness to market changes**, allowing manufacturers to quickly adapt their manufacturing processes to the market situation. The necessary **time to market**, as well as **unit quantities**, can be reduced, so manufacturers could have a competitive advantage compared to manufacturers using solely traditional manufacturing methods. Advanced Manufacturing also allows manufacturers to produce high-quality goods made to buyers' exact specifications.

Main challenges and requirements along the technological value chain

Efficient processes and production facilitated by digitalisation require **interconnectivity between factories**, exchange of **relevant data sets**, using sensor networks to gather necessary manufacturing data, and using new technologies (e.g. Augmented or Virtual Reality) to train new workers. Workers need to acquire specialised **digital and technical skills** to be able to make use of the full potential of advanced manufacturing. Our research and the interviews we conducted indicate, however, that there is still a struggle within the established industrial community to understand the overall expected benefits of advanced manufacturing in the manufacturing domain, leading to disadvantages in the context of remaining competitive on the market.[14]

Advanced manufacturing will pose a **challenge to the job market**, as some jobs will be at risk due to automation, e.g. in the context of 'predictive maintenance' or assembly lines. A gradual introduction of ICT in traditional manufacturing can minimise the negative impact while maximising the expected positive aspects. This should be combined with corresponding trainings in order to meet the required skill levels of the workers.

The EU is dependent on third countries for **access to many of the critical raw materials** required in the context of (advanced) manufacturing, e.g. **Lithium** from Chile, Australia, and China, **Gold** from China, Australia or Russia, or **Cobalt** from the Democratic Republic of the Congo and Canada. For this reason, appropriate trade agreements and contracts are used to overcome this shortcoming

[13] The 5G technology is an enabler for advanced manufacturing. It enables the integration of a large number of sensors on the manufacturing site and facilitates the advanced monitoring and control of the process.

[14] We identified during the interviews that very often the industrial community is reluctant to invest in advanced manufacturing and is basically sticking to old processes.

and secure access to such materials. Europe is trying, and should continue to try, to establish diversified supply chains in an ethical, fair and sustainable manner. Specific policy options to address this issue can be found in Chapter 4.

Box 2.1: Case Study - Tackling noise pollution and predictive maintenance with the help of acoustic cameras and artificial intelligence

Noise pollution is a hidden risk that is nearly as damaging as air pollution. According to the WHO, 1.6 million healthy life years are lost each year due to noise pollution.[15] Built on micro/nano-electronics, acoustic cameras encompass multiple microphones, from which audio signals are collected and processed. They can identify where the noise pollution is coming from and enable the visual representation of the noise pollution's location, as well as classification of the noise pollution (e.g. a group of people, public transport, breaking glass, etc.). In this way, the anonymised monitoring of sound pressure levels becomes much more insightful and builds the foundation for smart solutions. A Dutch company *Sorama*, in collaboration with the municipality of Katwijk, used acoustic cameras to investigate complaints about an undefined noise that kept citizens awake. With the acoustic cameras, the source was soon identified and the city of Katwijk took appropriate measures.[16]

In addition to the identification of noise pollution, acoustic cameras can also be used for **predictive maintenance** by detecting problematic sounds from manufacturing processes or vehicles passing by the cameras. Hereby, sound and ultra-sound can be used as an indicator for predicting an upcoming failure. The same Dutch company, *Sorama*, in collaboration with the municipality of Eindhoven, used acoustic cameras in the context of public transport and piloted the system with a focus on buses and trains.[17] The cameras were used to monitor and detect suspicious noise during operation and were able to recognise problems such as damaged wheels of trains or brakes that needed replacements. In that use case, AI was additionally used to make the underlying systems smarter and more accurate over time.

The aforementioned use cases showcase the enormous potential of acoustic cameras powered by AI and secured/interconnected by ICT in many different domains. The micro-chips of acoustic cameras ensure that only relevant, anonymised datasets and events are securely transferred over the network. The whole solution is considered as GDPR compliant, thereby increasing the overall trust in this solution.

KETs in this case study: Advanced manufacturing; micro/nano-electronics and photonics; AI; security and connectivity technologies

2.1.2. Advanced materials and nanomaterials

Definition and importance

Materials impact humans in almost every single aspect of life and have a huge impact on the environment, economy and society in general. This KET includes the research on **advanced smart materials** for the **fabrication** and **production** of a new generation of products. Generally speaking, advanced materials refer to materials (e.g. polymers, metals and alloys, glass, ceramics, composites, etc.) with new or improved properties that increase their performance over conventional products and processes. Advanced materials can facilitate the **transition** to more **sustainable technologies** with improved characteristics and enhanced performance. This is strongly aligned with Europe's goals in the context of the European Green Deal and industrial strategy.

Advanced materials and nanomaterials encompass different topics and applications including but not limited to:

15 World Health Organization. Burden of disease from environmental noise. 2011

16 Sorama. Smart City and selected customer stories. Website as of 10.02.2021

17 Sorama. Acoustic cameras and applicable industry domains. Website as of 10.02.2021

• Nanomaterials • Biomaterials • Tools and processes for the design and realization of new materials and resulting products	• Chemistry, physical and biological foundations as well as advancements for new materials • 3D printing and design	• Design of new products based on the new materials or advancements, especially in the context of chemicals, polymers, metals and alloys, glass, ceramics, composites, etc.

Potential applications

R&D in this area will enable **advanced processes** and **products** to be provided by the European industries while **reducing** the **negative environmental impact** and **positively influence European societies**. Advanced materials in the automotive sector will directly lead to reduced emissions having a positive impact on Europe's goal towards a sustainable future, which is directly related to the European Green Deal.

According to the US Office of Energy Efficiency & Renewable Energy: '*Advanced materials are essential for boosting the fuel economy of modern automobiles while maintaining safety and performance. Because it takes less energy to accelerate a lighter object than a heavier one, lightweight materials offer great potential for increasing vehicle efficiency. A 10 % reduction in vehicle weight can result in a 6 %-8 % fuel economy improvement*'.[18]

Future advancements in material-related research will **increase the competitiveness** of European products and companies on the global stage (e.g. automotive, aero-space industry, energy sector, etc.) thereby also **creating new jobs** in the corresponding industries.

Main challenges and requirements along the technological value chain

Similar to advanced manufacturing, securing **access to necessary raw and processed materials** is of utmost importance for the development of this KET. The transition towards a sustainable circular economy has the potential to help overcome the resource challenge. It will maintain the value of products and used raw materials for as long as possible, while at the same time minimising the generation of waste.

Since materials are so fundamental for the global economy, they have a heavy impact on supply and value chains. The main challenge is to focus on **flexible and lean supply chains** thereby enabling rapid prototyping and faster adjustments to market changes facilitated by digital enablers and other relevant developments. Europe should try to shape a viable path towards the creation of technological eco-systems that are socially and economically just. Improved technological eco-systems would lead to new jobs for the European economy. However, these jobs will require specialised digital skills that are currently in shortage.

[18] US Office of Energy Efficiency & Renewable Energy. Lightweight Materials for Cars and Trucks. Website as of 29 March 2021

Box 2.2: Case Study - European companies build smart touch-sensitive surfaces

To increase the user acceptance of new technologies, the design of human-machine interactions and the associated interfaces play an essential role. In this context, touch-sensitive surfaces have recently become particularly important. As the name indicates, touch-sensitive surfaces contain sensors that are capable of sensing touches, which are then translated into device instructions to provide visual or haptic feedback to the users. A widespread example of touch-sensitive surfaces are touchscreens.

European companies play an important role in R&D of touch-sensitive surfaces. Innovative and disruptive European technologies have enabled the flexible and space-saving use of touch-sensitive surfaces on many materials, while achieving consistent quality and high reliability. As a result, the application of touch-sensitive surfaces has been extended to sectors such as automotive and aerospace. For example, *TactoTek*[19], a Finnish company founded in 2011 and funded by the European Commission under the Horizon 2020 programme[20], has developed a licensed and proprietary Injection Molded Structural Electronics (IMSE) technology. The IMSE integrates printed circuitry and electronic components on three-dimensional (3D) surfaces in almost any shape. This enables a flexible, space-saving, lighter and smart molded application of novel touch-sensitive control elements. An inspiring pilot product for the automotive sector is the *Origo Steering wheel*[21]. It allows 3D thumb control, providing natural, mobile phone like end-user interaction with assisted or semi-assisted cars.

Another European company making promising progress in this field is the French company *Nanomade*[22] founded in 2009. *Nanomade* has developed and patented a sensing technology based on a proprietary and transparent ink consisting of nanoparticles. This sensing technology can be applied to any surface and in any shape, forming it into multi-touch and multi-force sensitive surfaces. According to *Nanomade*, this technology enables the development of flexible and low-cost 3D touch solutions for displays and any rigid or flexible surface.[23]

KETs in this case study: Advanced materials and nanomaterials; micro/nano-electronics and photonics; advanced Manufacturing

2.1.3. Life-science technologies

Definition and importance

In general, life-science technologies can be seen as an **intersection of engineering and life sciences** dealing with the technical use of findings related to life science, especially in the interrelation of biology, automation and digitalisation. On the one hand, the profound understanding of the functioning of living systems enables **the production of new or improved products** as well as **processes** for e.g. the pharmaceutical/chemical industries or for environmental technology. On the other hand, knowledge related to engineering is needed to **integrate biological systems into technical processes** (e.g. the production of pharmaceutical ingredients in sufficient quantity and quality). The **Covid-19 pandemic** has shown that the sufficient production of high-quality vaccines is a very complex task, influenced by many different stakeholders and dependent on different raw materials, reinforcing the importance of this KET with respect to technological sovereignty. This is strongly aligned with Europe's goals in the context of Horizon Europe (especially in the health cluster).[24]

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19 TactoTek. TactoTek. Website as of 12 February 2021

20 investEU – European Commission. Lighter, Sturdier Touch-Sensitive Electronics. Website as of 12 February 2021

21 Canatu. Origo Steering Wheel Concept. Website as of 12 February 2021

22 Nanomade. Nanomade - Make All Materials Smart. Website as of 12 February 2021

23 Nanomade. Touch Sensor Panel - Nanomade. Website as of 12 February 2021

24 European Commission. Horizon Europe structure and the first calls. Website as of 29 March 2021

As already noted, the pharmaceutical, chemistry, and cosmetic industry can particularly benefit from this KET by developing new products and processes based on life and science research. However, the field of life-science technologies encompasses many different topics and applications including but not limited to:

• Biological data analytics • Machine Learning applications in biology • Lab-on-a-chip	• Cell and tissue engineering • Neurotechnology • Genomics including synthetic genomes	• Bioelectronics • Biomaterials in general • Bioengineering

Potential applications

Based on the most promising use case scenarios in the context of life-science technologies, Europe can transition to a **resilient and healthier European society** in terms of new medical achievements and applications such as optimised pandemic responses, innovative products based on conducted research or technological implementations. For example, lab-on-a-chip[25] is envisioned to facilitate automation and **high-throughput screening** which is especially relevant in the context of the Covid-19 pandemic. The positive impacts are not limited to health only, they can also be expected in the domains of **agriculture, medicine, pharmaceuticals** and **food science**.

Main challenges and requirements along the technological value chain

Life-science technologies use specialised **raw materials** (such as lipids, cells) for research and for high-quality and high-quantity production. Similar to other KETs, here we observe a strong dependence on non-European suppliers, which became especially acute during the Covid-19 pandemic. For example, appropriate trade agreements and diversified supply chains are required to address pricing policy, price pressure, and other challenges. Specific policy options can be found in Chapter 4.

Collaboration between life-science technologies and the healthcare systems[26] of European countries is rendered more difficult by budget cuts. National healthcare systems are requested to deliver high quality and timely services based on the latest advancements in global research, while health budgets are increasingly under pressure as governments try to reduce overall spending. Life-science technologies directly impact our healthcare systems by providing new medications or by developing new treatments for diseases, leading to increased life expectancy and improved quality of life for all Europeans. The corresponding downside of this is that European countries are challenged to allocate additional budget for the social protection and care of the elderly to minimise the growing risk of old-age poverty.

2.1.4. Micro/nano-electronics and photonics

Definition and importance

The micro/nano-electronics and photonics relate to all types of digital and computing technologies in the magnitude of **high-performance computing** and **communication based on micro/nano-electronics**. The major goal of micro/nano-electronics is to **improve the performance of electronics**, while at the same time reducing their size, weight and/or power requirements. Thus,

[25] A lab-on-a-chip integrates and automates multiple laboratory techniques on a single chip of up to a few square centimetres in size. This enables manipulating reagents on the microscale, which in turn enables exploiting effects such as rapid heating and mixing, and it also allows minimising waste and exposure to dangerous chemicals. From: https://www.nature.com/subjects/lab-on-a-chip

[26] The current context relates to the collaboration between research institutes, technology companies in the domain and entities from the healthcare systems (e.g. hospitals). This could cover different studies including the piloting of new technologies.

micro/nano-electronics play a **fundamental role in further digitalisation** or **technological advancements** in general. The micro/nano-electronics and photonics also relate to computing based on photonic principles – i.e. **optical/photonic computing** - that uses photons produced by lasers or diodes for computational aspects, in order to provide an alternative computing approach with **improved characteristics related to bandwidth, signal loss**, etc. compared to traditional computing. Thus, this KET is strongly aligned with Europe's industrial strategy. This field of micro/nano-electronics and photonics encompasses a number of topics and applications including but not limited to:

• High-Performance Computing • Micro- and nano-electronics for IoT sensors and tokens • Integrated circuit design • High-Speed Optical Networks, Protocols and Standards	• Quantum-IT • Quantum Computing • Quantum Communication and Quantum Key Distribution • Quantum Sensing • Cloud Quantum Computing	• Methods and Tools for Quantum Software Development • Processes and support for handling NISQ (Noise Intermediate Scale Quantum) computing aspects • Development and application of QC to real world problems

Potential applications

Micro/nano-electronics **play a fundamental role in many different application domains** in our everyday life as well as in support of other KETs. Their range of application is enormous: smartphones, laptops, automotive, aviation, robotics, industrial automation, health, medicine, lab on chip, sensor networks, additive manufacturing, smart cities, logistics, pandemic prevention and more. **Advancements related to micro/nano-electronics directly influence the lives of every European citizen** and are of paramount importance in order to stay competitive on the global market.

In addition, a special focus should also be put on the future **application of quantum technology**, in order **to maintain and improve the competitiveness** of the European industry and society. Furthermore, the overall digitalisation pushed by such technologies is a game changer on a global scale.

Main challenges and requirements along the technological value chain

The highly specialised domain of micro/nano-electronics and photonics require highly educated researchers and industrial experts, who are in deficit in Europe. In addition, the supply and value chains in these domains often encompass non-European suppliers and know-how carriers, and European research results are mostly commercialised in third countries. The **dependency on non-European manufacturers puts Europe in a weaker position** in the global geo-political competition. The main challenges are, therefore, to bring back some of these supply/value chain parts and know-how to Europe and to foster a new generation of experts, who not only have the potential for research-related breakthroughs but also for the commercialisation of research, strengthening the position of Europe.

Quantum computing hardware is experiencing **challenges on the fundamental-science level**, i.e. instability of the basic computing units (qubits), which compute results that are still heavily influenced by noise and are hence imprecise. Targeted research on fault-tolerant computing is required to reduce error rates.

In general, further digitalisation of society will lead to higher productivity, but this benefit is strictly correlated to **acquiring specialised digital skills** or the re-education of all European citizens and the working force in particular. The inclusion of all generations in relevant programmes will facilitate a just transition to a more digitalised society.

Box 2.3: Case Study - A closer look into extreme ultraviolet (EUV) lithography

Integrated circuits ('chips') that are at the heart of micro-/nano electronics are getting smaller and smaller implying the need for more advanced techniques and extremely complex machines to produce these integrated circuits. One of the newest trends is using **extreme ultraviolet (EUV) lithography**. EUV lithography is currently replacing the classic photolithography in semiconductor technology and will **enable a more economical and efficient production of microelectronic circuits but also the development of circuits with higher component densities.**

Only a few companies are suppliers of EUV lithography systems for the semiconductor industry; the largest supplier globally is ASML from the Netherlands, strengthening Europe's global position on this specific market. The EUV machines produced by this Dutch company '*use extreme ultraviolet (EUV) light beams, generated by lasers and focused by giant mirrors in order to lay out extraordinarily narrow circuits on slabs of silicon known as wafers. That in turn makes it possible to create faster and more powerful microprocessors, memory chips and other advanced components which are critical for consumer electronics and military applications alike*'.[27] In 2017, the Dutch company was the only supplier ever to deliver the first twelve EUV machines to customers with a total value of ~€1 4 billion for all twelve machines.[28]

EUV lithography will become more relevant in the coming years and, thus, it is of paramount importance to recognize this opportunity for Europe, to further strengthen Europe's position in this context, to ensure that the critical know-how remains in Europe and to avoid the brain drain.

KETs in this case study: Micro/nano-electronics and photonics.

Box 2.4: Case Study - Shortage of semiconductor chips in the German automotive sector

In early 2021, serious information agencies reported that the European automotive industry experienced a severe problem on the path to its recovery from the Covid-19 pandemic.[29] The specific problem was a shortage of semiconductor chips, which are playing a vital role in modern cars heavily equipped with electronics (navigation systems, touch screens, cruise control, etc.). Modern cars steer many of their functions over specific control loops requiring digital solutions and correspondingly semiconductor-chip-based components. The shortage concerns both car manufacturers (e.g. Volkswagen, BMW, Mercedes-Benz) and their suppliers (e.g. Bosch, Continental) of various modules to be integrated during the car assembly.

The automotive industry had to slow down and reduce production levels at the beginning of the Covid-19 pandemic (early 2020) leading to the stalling of complete supply chains spanning the globe from Asia to Europe. However, as of early 2021, an uptake was obviously expected based on predictions and available contracts. The discussed shortage appears to be an issue leading to significant delays and stems from the slow production uptake in Asia, where vendors aim to first satisfy their main customers – namely the producers of smart phones, tablets, laptops, game consoles and entertainment electronics in general (e.g. Apple and Samsung). European suppliers of semiconductor chips are available only at a very limited scale and mostly target specific niches of the market.

Indeed, in this case it can be observed how dependence in a key KET on non-EU suppliers can endanger the post-COVID recovery of a key industrial field of the European economy. As of February 2021, the situation is still unfolding and even leading to discussions on political level[30] as German car manufacturers are approaching chancellor Angela Merkel to politically handle the circumstances relating to key partners from Asian countries, e.g. Taiwan.[31]

KETs in this case study: Micro/nano-electronics and photonics.

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[27] Alper Alexandra, Sterlin Toby, and Nellis Stephen. Trump administration pressed Dutch hard to cancel China chip-equipment sale: sources. 06.01.2020

[28] Taipei Times. Dutch firm ASML perfecting 'the shrink' for microchips. 14 May 2018

[29] Pandey Ashutosh. Computer chip shortage disrupts global car production. 14 January 2021

[30] Financial Times. German carmakers enlist Merkel as they battle chip shortage. Website as of 14 February 2021

[31] Nienaber Michael. Germany urges Taiwan to help ease auto chip shortage. 24 January 20201

2.1.5. Artificial intelligence

Definition and importance

AI is the **science and engineering of developing intelligent systems which perform tasks that typically require human intelligence**. It comprises intelligent decision making based on automated choices, which are obtained by algorithms processing predefined rules or analysing large amounts of data, learning the decision models and applying these models in particular situations. **Modern AI-based algorithms and systems are mainly driven by huge amounts of data**. The superordinate goal is to detect patterns in the available data, which are later used during the decision-making process. Therefore, the increasing availability of data and the tremendous advances in computing power are key drivers of the current success and boom of AI.

AI finds application in many fields such as medicine, transportation and logistics, mobility, smart cities and many more. Thereby, specific fields of application are complex and diverse. The following list includes some relevant areas of application and research for AI:

• Development and domain specific application of algorithms and models for machine learning (ML) • Quality of AI based decisions • Explainability and Transparency of AI-based algorithms • Certification of AI algorithms	• Quantum AI and Quantum Machine Learning • AI applications for SMEs and for large scale industry • Artificial intelligence for Smart Cities and Communities • Quality of training and test data sets	• AI-as-a-Service provided by platforms located in EU • Privacy Preservation within AI processes and frameworks • Ethical and fairness aspects for AI to meet EU values

Potential applications

Large amounts of data are available over IoT platforms and Open/ Big/ Commercial Data Platforms across the EU. Utilizing such data sets and processing them with state-of-the-art AI techniques will lead to new products, optimised processes and improved industrial processes in many domains. It will increase the quality of life across Europe. **AI has the potential to revolutionise manufacturing** by improving or automating many industrial processes. This can help to counteract the shortage of skilled labour and strengthen European industry. AI can also be used for predictive maintenance to increase the lifetime and reliability of industrial facilities and production lines. The use of **AI in the field of mobility and autonomous** driving holds enormous potential for Europe. It can help to reform the European car industry by **developing new technologies and business models** to make this industry more sustainable and future-proof. In mobility, AI can disrupt the traffic and public transport sector in many European cities. Automation and intelligent transport systems can reduce costs and enable the implementation of cleaner transport systems. The high amount of traffic in many European cities can be reduced through the additional demand-oriented usage of shared self-driving cars. These actions will result in a sustainable reduction in environmental pollution and noise levels. In the long-term, this will increase the quality of life and make European cities more attractive to live in.

AI has a great socio-economic potential. AI can be used to develop new business models and help to counteract the shortage of skilled labour. **AI can be applied in the medical sector and healthcare systems** which will result in an increase in the quality of life. For example, AI can be used to develop new medications and treatment therapies, to improve diagnostics and prevention of diseases and to support trained medical professionals. Finally, AI can contribute to the **mitigation of climate change** through intelligent energy and waste management and automated analysis of climate data.

In conclusion, the EU can combine its academic, technological, and industrial strengths with a high-quality digital infrastructure and a regulatory framework based on its fundamental ethical and moral values to act as a forerunner in innovation in the data economy and its related AI-based applications, as envisaged in the *European strategy on artificial intelligence.*[32]

Main challenges and requirements along the technological value chain

AI is a general-use technology and, therefore, of paramount importance for the further technological development of Europe. Due to this, challenges to AI research, technology, business and socio-economic challenges should be urgently addressed.

Since AI algorithms are driven by data, **the availability, quality, and integrity of datasets** is one of the most challenging requirements associated with AI. Availability of data to all EU citizens through Open Data portals, Geo-Information Systems, IoT networks, and various one-stop-shop platforms is critical.

The use of AI in safety-critical areas such as manufacturing, medicine, energy management, or autonomous driving means that **safety and functionality** must be ensured at all times. **Explainability, accountability, and transparency** of AI-based algorithms and applications is another crucial challenge, which has not yet been solved and must be a focus of further research. Black-box AI systems cause uncertainties in automated decision-making and entail not only security risks but also legal challenges. Explainability and transparency are also basic requirements for the **standardisation and certification** of AI algorithms and applications – which is another significant challenge. Standardisation and certification should ensure both the quality and dependability of AI systems as well as their compliance with the EU's ethical requirements. This is an area where the EU has the potential to take a leading role internationally.

The recruitment of highly **skilled researchers and workers** experienced in mathematics, stochastics, and computer science needs to be ensured and the current **brain drain** reversed. Europe struggles to attract and retain international talent, and European companies (especially SMEs) suffer from the lack of financial resources to establish internal teams of experienced AI experts, which currently prevents businesses from using AI for business model innovation. The emerging cloud-based AI-as-a-Service (AIaaS) helps to address this challenge as it requires less experienced personnel and therefore gives SMEs a fair chance to use AI.

[32] European Commission. Shaping Europe's Digital Future - Artificial Intelligence. Website as of 26 February 2021

Box 2.5: Case Study - Quantum artificial intelligence

AI encompasses various important algorithms and methods from the field of machine learning (ML) and deep learning (DL), which analyse and process large amounts of data and recognise (statistical) patterns. Semantic AI technologies – dealing with semantic knowledge representation and interpretation with logical reasoning - and other AI algorithms (e.g. from the field of planning and optimisation) are used to enable (semi-) autonomous decisions and actions of an AI based agent/system. Possible applications are in the field of autonomous, cooperative and learning systems and can be physically embodied as robots or 'smart' devices, as well as digitally represented as web agents, cognitive assistants or intelligent services.

However, AI, ML and DL require intensive utilisation of computing power, and the necessary amount of computing resources increases constantly. In the long run, a real 'quantum leap' in terms of computing power will be necessary if the potentials of AI are to be further exploited and expanded. Breakthroughs at this frontier should come from new computational models such as quantum computing (QC). Moreover, the combination of QC and AI offers the possibility of integrating the advantages of QC into commercial applications. QC technology has great potential to make AI significantly more powerful and increase its application domains.

The first quantum computers are already commercially available or are about to be launched on the market. The point at which quantum computers can solve problems that traditional computers can practically no longer deal with - a so-called quantum advantage - is well within the realm of possibility in the next few years. However, Quantum AI comes with different challenges for our societies. For example, the issue of trustworthiness and the associated certification of AI and machine learning algorithms and systems is of great importance for the acceptance of AI in our societies and its application in critical infrastructures and services. The same applies equally to Quantum AI. Therefore, there is an intrinsic challenge to research and identify approaches and methods to make Quantum AI algorithms explainable, in such a way that they can be the subject of certification tests and evaluations by the relevant certification bodies/organisations.

KETs in this case study: AI; micro/nano-electronics and photonics.

2.1.6. Security and connectivity technologies

Definition and importance

This KET stands for various ICTs and their cyber-security aspects. The security and connectivity technologies are a fundamental enabler and building block for other KETs and for digital transformation. These technologies are ubiquitous due to the ongoing digitalisation and growing deployment of IoT devices.

Recent developments in the Covid-19 pandemic also demonstrate the enormous need and relevance of this KET. The pandemic indicates that developments and improvements in communication and security technologies are key requirements for the digitalization and related aspects such as (digital) home-schooling and home office. Despite infrastructural, technical, and administrative difficulties, the latter aspects in particular proved to be an effective element in coping with the pandemic and managing it.

Concrete applications and examples of these technologies are manifold and diverse, for instance:

• Communication and network protocols and technologies • Large-scale and Europe-wide IoT networks • FTTx (Fibre to the X) deployments • Certification methods for network and software architectures	• Operating systems and platforms for digital services and applications • Network components – routers, firewalls, intrusion detection/prevention systems for critical infrastructure • Quantum Key Distribution • Cryptography and its security implications	• Post-quantum cryptography • Activities in the scope of national and international standardization bodies • Structure and the security of telecommunication networks • Distributed ledger technologies (e.g. blockchain technology)

Potential applications

Technologies based on this KET will lead to **increased connectivity, digitalisation, and cyber-security** in Europe and result in a larger set of optimised processes, increased quality of life, and better services for European citizens. Therefore, the use and further development of these technologies support the EU strategies towards advanced *Connectivity for a European Gigabit Society*[33] and *Cybersecurity.*[34]

Specifically, this KET will enable the **development of new, better, and more secure digital services with high quality** for European citizens. These can increase quality of life and will additionally enhance the attractiveness of Europe by accelerating digitalisation. Security and connectivity technologies will intensify and speed up the **deployment of IoT devices**, which will also boost the **development of (open) IoT platforms**. This wide-spread roll-out of IoT devices will enable the **autonomous and secure collection of data** on a larger scale. The gathered data can then be used to analyse many processes in more detail, gain deeper insights, and subsequently optimise them. Besides, as mentioned in Section 2.1.5, data is a key enabler for AI, hence the gathered data can additionally contribute to accelerating the progress of the AI KET. Both the collected data and the improved connectivity provided within this KET offer the potential to **develop new and innovative business models** and strengthen European industry.

Main challenges and requirements along the technological value chain

Security and connectivity technologies will continue to influence almost every aspect of our societies due to the steadily advancing digitalisation and the continuing uptake of IoT devices. The main challenge is to **develop these technologies according to European values and regulations**, ensuring that they meet European standards and safety requirements. The ongoing development of these technologies must be permanently guaranteed to **keep up with the ongoing cybersecurity race** with attackers and hackers. Detected vulnerabilities are closed immediately, mitigating cyber threats and guaranteeing security of critical infrastructures.

A crucial challenge is the **lack of large and influential IT companies** in the field of security and connectivity technologies in Europe. Europe is reduced to the role of a user and depends on hardware and software from few non-European players. This dependence on a few players could also end up in a vendor lock-in. Development of open interfaces, open standards, open-source software, European standardisation and certification can help overcome these risks. The open standardisation and certification approach enables a modular and vendor-independent integration and replacement of software and hardware components. European players need support in their

33 European Commission. Shaping Europe's Digital Future - Connectivity for a European Gigabit Society. Website as of 26 February 2021

34 European Commission. Shaping Europe's Digital Future - The Cybersecurity Strategy. Website as of 26 February 2021

research activities and in developing new business models to create open eco-systems and a diverse portfolio of available products and equipment alternatives for critical infrastructures.

Similar to AI, while the EU can boast successful research activities in the field of security and connectivity technologies, it **lags behind in commercialising** and retaining commercialised products in Europe. The majority of successful business models and products come from non-European players. Many European scientific results in the sense of commercialised products as well as researchers are systematically acquired by non-European stakeholders, leading to a **brain drain** and compromising European industry and academia.

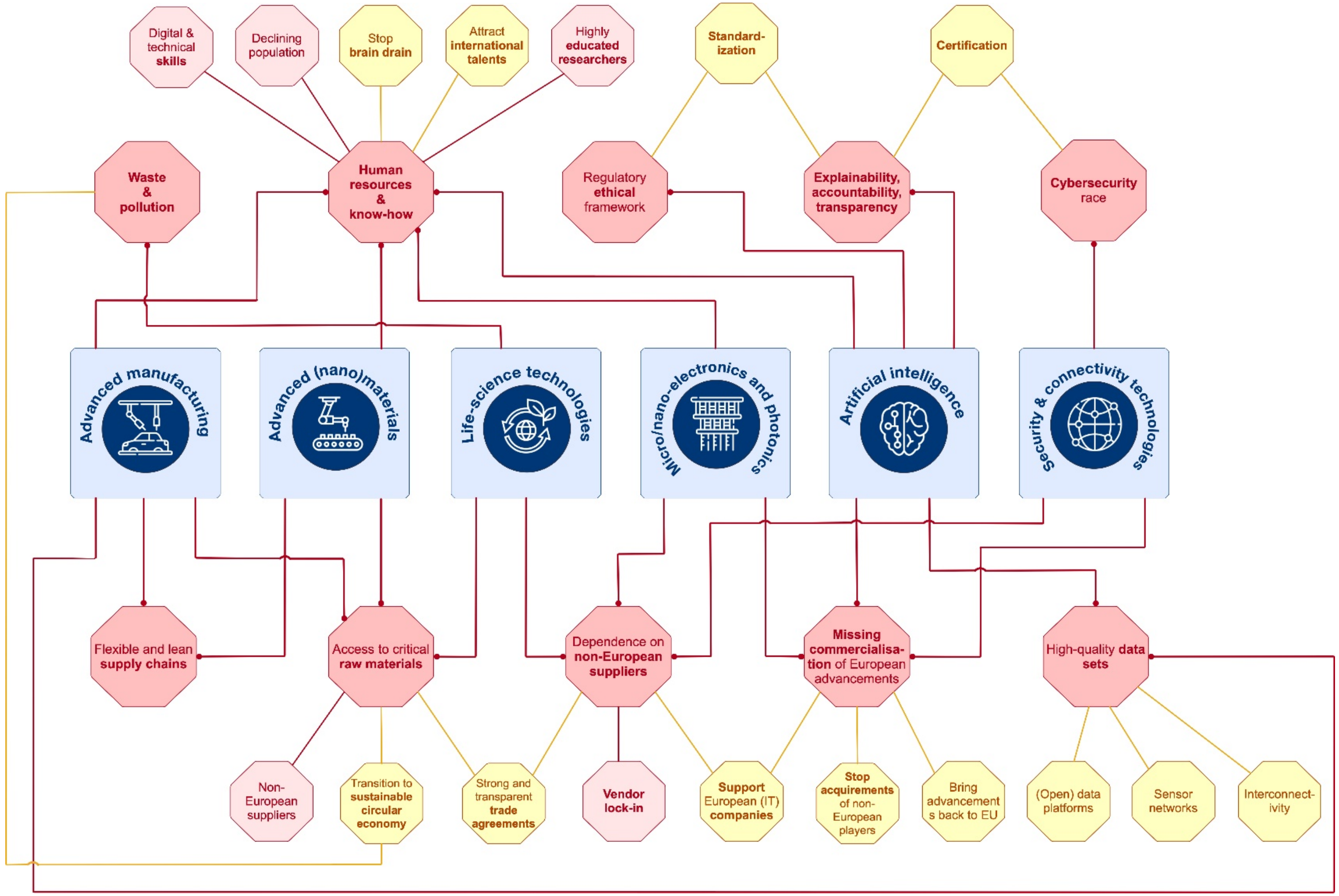
2.2. Global analysis of the KETs

The following subsections analyse the KETs from a global perspective, visualising and summarising the main challenges and applications relevant for all KETs. We describe the most important challenges and impacts as well as the relationship between the KETs in more detail. This subsection concludes with a short reflection on the importance of each KET for Europe's society and competitiveness.

2.2.1. Overview of challenges

Although the challenges related to the KETs are manifold (see Figure 2.2), we focus on the four most important challenges from a global perspective, as identified in our assessment and derived from the interviews and literature review.

Figure 2.2: Summary of challenges



Note: Red indicates major challenges and light red indicates corresponding sub-challenges. Yellow indicates some calls to action. Source: Authors' own work.

Lack of resources / raw materials

Lack of resources/ raw materials

Europe is dependent on other countries and continents for access to many of the critical raw materials or resources needed in the context of the KETs (e.g. advanced manufacturing, advanced (nano)materials, life-science technologies, etc.). The lack of natural resources is a fact that cannot be changed, thereby implying the need for strong and transparent trade agreements as well as ethical, fair and sustainable supply chains that are sufficiently diversified to enable Europe to remain competitive. Furthermore, recycling and a circular economy help ensure availability of resources. In addition, data – as a fundamental enabler for AI - can also be seen as a resource. However, as of now, the large amount of high-quality datasets needed is not available to the vast majority of European stakeholders. Initiatives aimed at creating common data resources exist already and should be further supported. Additional, specific policy options can be found in Chapter 4.

Dependence on non-European suppliers

Dependence on non-European suppliers

Micro-/nano electronics and photonics are among the fundamental enablers for many KETs (see Section 0) and other technologies. As of now, many of the supply and value chains in this KET depend on non-European stakeholders and know-how carriers. Thus, dependency on non-European manufacturers puts Europe in a weaker position in the global geo-political competition. This is also true for other KETs, e.g. life-science technologies. Therefore, the associated main challenge is to bring back some parts of these supply and value chains and know-how to Europe. Again, strong and transparent trade agreements as well as sufficiently diversified supply chains need to be put in place in order to ensure Europe's competitiveness and its position in the global economy. Specific policy options are presented in Chapter 4.

Digital skills

Digital skills

In general, one of the expected, positive impacts of the KETs is related to a more digitalised and connected society that makes efficient use of a variety of technologies (e.g. additive manufacturing, lab-on-a-chip, IoT sensor networks, etc.), which in turn would lead to new jobs for the European economy. However, these impacts are dependent on workers and end users acquiring specialised digital and technical skills to be able to make use of the full potential of the KETs. There is still a lack of understanding within the industry of the overall expected benefits of some of the KETs, e.g. advanced manufacturing. In addition, it is of utmost importance to shape a viable path towards the creation of technological eco-systems that are socially and economically just. Policy options addressing this challenge are detailed in Chapter 4.

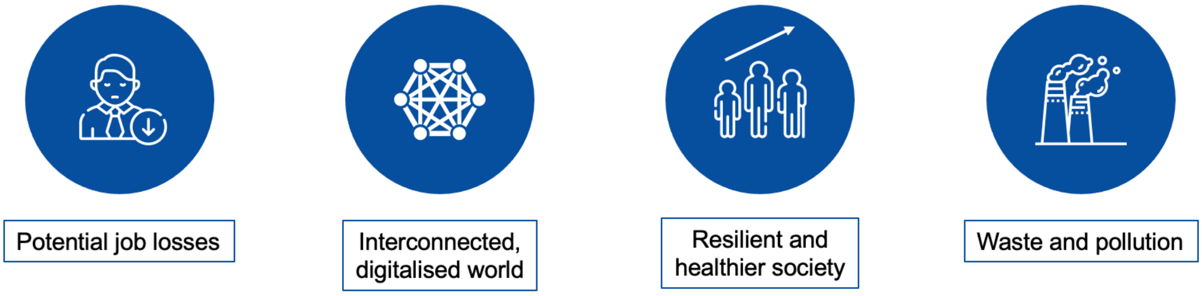
Commercialisation of research results

Across all KETs, European research activities are quite successful and are advancing steadily. However, the EU lags behind in commercialising research results - among other things because of the lack of venture capital - and retaining commercialised products in Europe. The majority of successful business models and products come from non-European stakeholders. Furthermore, many European scientific results and researchers are systematically acquired by non-European stakeholders. As a result, a lack and drain of technological experts and know-how can be observed, compromising European industry and academia, as these are missing to translate scientific results into commercial products. In addition, the lack of large, European IT companies that could prevent the systematic acquisition and itself attract international talent is a related challenge (this is especially relevant in the KETs related to security and connectivity). Specific policy options are detailed in Chapter 4.

2.2.2. Impact summary

The expected impacts of the KETs are manifold (see Figure 2.4 for an overview of positive impacts). In the following paragraphs, we describe the four most important positive and negative impacts from a global perspective, which we derived from interviews and a literature review.

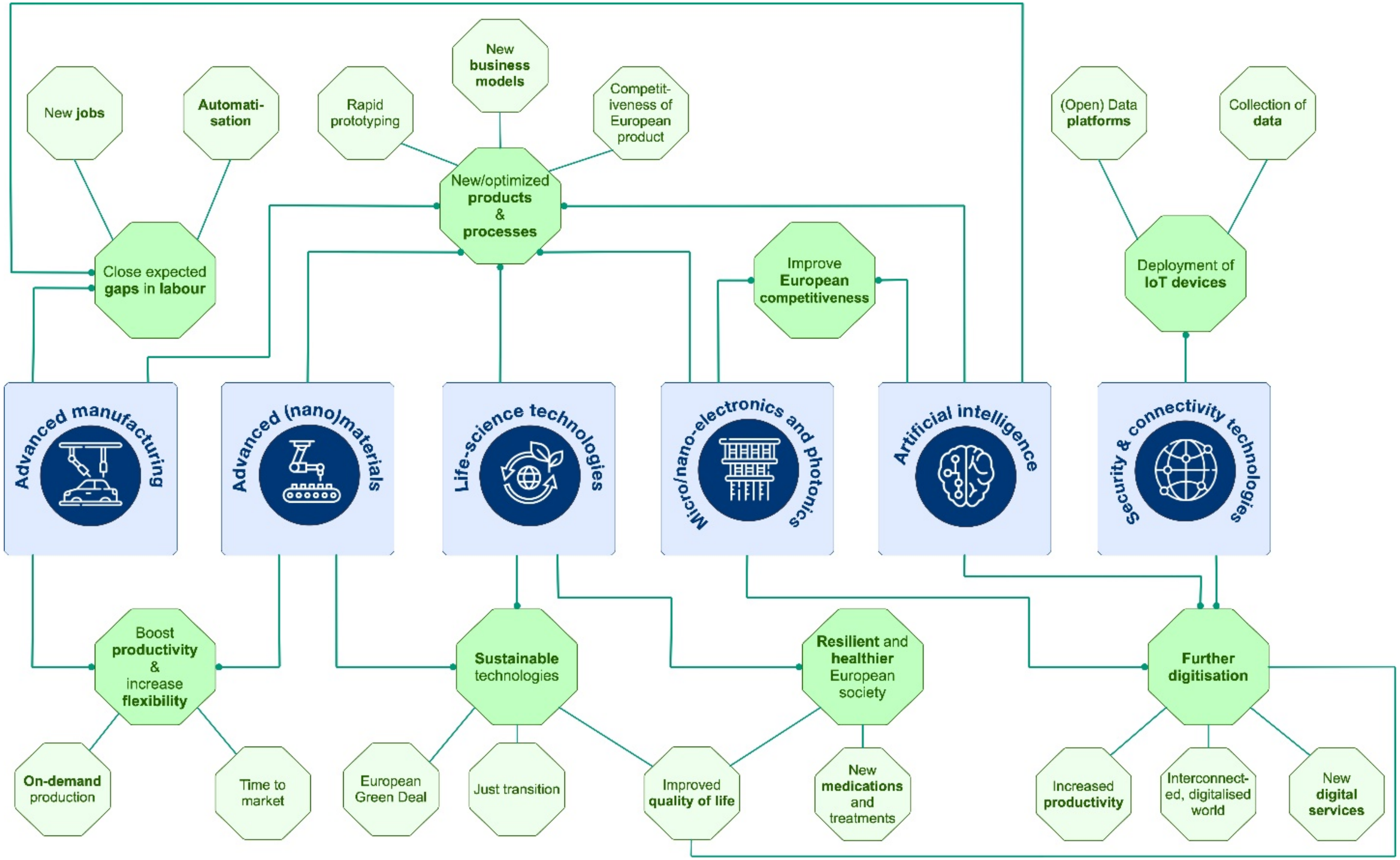
Figure 2.3: Main potential impacts of the KETs



As already noted, the use of technologies in different application domains leads to an **interconnected and digitalised society**. In general, this is a very positive impact for EU citizens because they can access the latest technological advancements, which directly improves their lives and enables them to overcome existing challenges. In addition, an interconnected and digitalised Europe is important for Europe's competitiveness and position in the global economy. It enables companies to improve their efficiency and to produce smarter, cheaper and in larger quantities. This positive impact should be embraced, and it should be ensured that the integration of KETs in the economy and society is socially and economically just. This is especially relevant whenever the introduction of technologies **endangers jobs** or **requires new digital skillsets**. For example, the introduction of robotics in manufacturing processes is a transition that could make many existing jobs obsolete in the near future. Therefore, Europe should carefully consider the impacts of KETs and should focus on a just transition making sure that no one is left behind.

The introduction of technologies – especially life-science technologies and health applications – is expected to lead to a more **resilient and healthier European society**. A healthier European society has a positive impact on Europe's competitiveness because the workforce is capable of working longer while considering an optimal work-life balance. The transformation to an interconnected society has also an environmental impact related to the creation of **(electrical) waste and pollution**. A strong focus should be put on the circular economy trying to maintain the value of products and raw materials for as long as possible, while at the same time minimising the generation of waste. New technologies such as AI could help in improving processes and reducing waste, while others such as advanced materials could reduce emissions. Raising awareness of waste and pollution are also of utmost importance in order to empower citizens to counteract this negative impact.

Figure 2.4: Summary of expected positive impacts



Note: Green indicates major positive impacts and light green indicates corresponding sub-impacts. Source: Authors' own work.

3. KETs, technological sovereignty and leadership

This chapter aims to provide an **assessment of how Europe is performing with respect to technological sovereignty in the six KETs, in line with the definition we suggested in the chapter 1, particularly from the research and industrial perspective**. It is structured as follows:

- A short introduction to the **methodology to identify the indicators** that are relevant to assess technological sovereignty. A detailed explanation of the methodology is provided in Appendix 2 - Methodology for the selection of indicators and related sources
- An **analysis of the following critical 'ingredients' to reach technological sovereignty: R&D&I funding, education/skills, innovation, entrepreneurship and industrial ecosystem**. Each of these elements is associated with the indicators for which Europe will be compared to third countries, especially the USA and China;
- A **global assessment of Europe** as regards technological sovereignty.

The selection of indicators, as well as the analysis, are based on data collected through desktop research and inputs from interviews with experts from industry and academia.

3.1. Technological sovereignty assessment

3.1.1. Selection of indicators

Objective

For this study, the aim is to derive **indicators to reflect EU performance** with respect to the definition of technological sovereignty developed in the Chapter 1 and consequently to determine Europe's position with regard to third countries. Thus, indicators have been selected to highlight Europe's strengths that need to be maintained or reinforced, but also Europe's weaknesses in critical areas that need to be addressed, showing the risk of dependence on third countries.

Identification of the indicators

Based on interviews, desk research and outputs from section 2, the study identified key 'ingredients', i.e. elements that are critical to reach technological sovereignty with regard to KETs- related research and industry. These are **ingredients, because several elements need to be combined to reach the technological sovereignty objective**, e.g. industry leadership will not be reached without research and *vice versa*. As stated in the definition in Chapter 1, ensuring the welfare of European citizens and the prosperity of businesses, as well as having the ability to act and decide independently in a globalised environment, the sovereignty in technology is about developing, providing, protecting, and retaining critial technologies. Accordingly, the list of ingredients translates those actions:

- Develop : the capacity of developing R&D competencies and knowledge thanks to the support from public and private sectors reflected under the ingredient of R&D&I funding;
- Provide: the capacity to turn R&D into market products and the reduction of dependence to third countries by having the right industrial ecosystem through the creation of start-ups and the leadership in critical technologies;
- Protect: the capacity to achieve and preserve the leadership by favoring the delivery of innovation through patenting and co-inventions;
- Retain: the capacity to maintain competencies and knowledge through adapted education and skills to ensure having the necessary qualified people in research and production in critical technologies.

For each of these ingredients, indicators were associated and then assessed in terms of relevance for technological sovereignty. A **selection of indicators was made according to the availability of the data**. Typically, the KETs Observatory developed by the European Commission is a good basis, despite some limitations.

The KETs Observatory set up by the European Commission through the Advanced Technologies for Industry (ATI) project[35] aimed to measure, compare and analyse the EU Member States' performance in the 6 KETs, as defined in the communication 'A European strategy for Key Enabling Technologies – A bridge to growth and jobs'.[36] Today, **the data dashboard as part of the Observatory does not cover the exact six 'current' KETs**[37], some indicators are not KET-specific, while others fail to encompass non-EU countries comparisons (and are thus not useful for assessing Europe's relative performance).

It should be noted that research and technology infrastructure was also included among the ingredients, however due to a lack of reliable and available indicators, this was left out of the assessment (see Appendix 2, section 6.2.2).

Constraints

Furthermore, some constraints had to be taken into consideration when selecting the indicators. Evaluating technological sovereignty for the six KETs is highly challenging. Almost all of the interviewees emphasised the difficulty of providing adequate indicators and reflecting all types of stakeholders when using official statistics as well as the difficulty of avoiding the introduction of biases. The difficulties in developing indicators to evaluate technology sovereignty lie in:

- Defining relevant indicators in line with the European vision (i.e. the absence of European definition of technology sovereignty, thus lack of common strategy);
- Having the same level of information covering the six KETs (absence of homogenous indicators on economy/industry covering the different KETs);
- Existence and availability of such data today and in the future for monitoring;
- Availability and reliability of data (e.g. no data exists to assess research and technology infrastructures);
- Availability of the same data covering third countries;
- Biases introduced in the established rankings (e.g. the ranking for universities and research centres are highly controversial due to the heterogeneous methods used, especially when covering different regions);
- Biases introduced by matching a sector with a KET;
- Authors' subjectivity in assessing the indicators qualitatively.

Based on our research and given the above constraints, we provide suggestions for further developing appropriate indicators in Appendix 2, section 6.2.3

Result of selection of the indicators

Based on the availability and collectability of the data, the result is presented in Table 3.1 below with the **selection of ingredients and eight associated indicators**. As shown, some indicators are specifically detailed by KET and others not. The combination of those ingredients and indicators aims to provide an assessment of EU position with regard to technological sovereignty.

[35] By a team led by IDEA Consult, in partnership with TNO, ZEW, NIW, Fraunhofer ISI, CEA and Ecorys conducted in 2013-2015.

[36] Communication from the Commission, COM(2012) 341

[37] E.g. 'life sciences technologies' is not the designation used, but 'industrial biotechnology'

Table 3.1: Indicators used to assess technological sovereignty

Ingredients for technology sovereignty	Indicators	Type of indicator
R&D&I funding	Domestic R&D intensity	Global
	Amount of public research programmes funding	Global
	Business/private R&D expenditures	Global
Education/skills	Number of STEM graduates	Global
Innovation	Share in global patenting	KET-specific
	Share of international co-inventions	Global
Entrepreneurship	Number of start-ups	KET-specific
Industry ecosystem	Industrial leaders ranking	KET-specific

Source: Authors' own work.

3.2. Analysis of research and industrial leadership

3.2.1. Research and Development and Innovation (R&D&I) funding

Investments in the KETs are one of the key drivers for the development of technological sovereignty. It is necessary to finance R&D, develop infrastructure, and support the ecosystem. This sub-section will analyse different key indicators regarding the R&D&I funding of KETs.

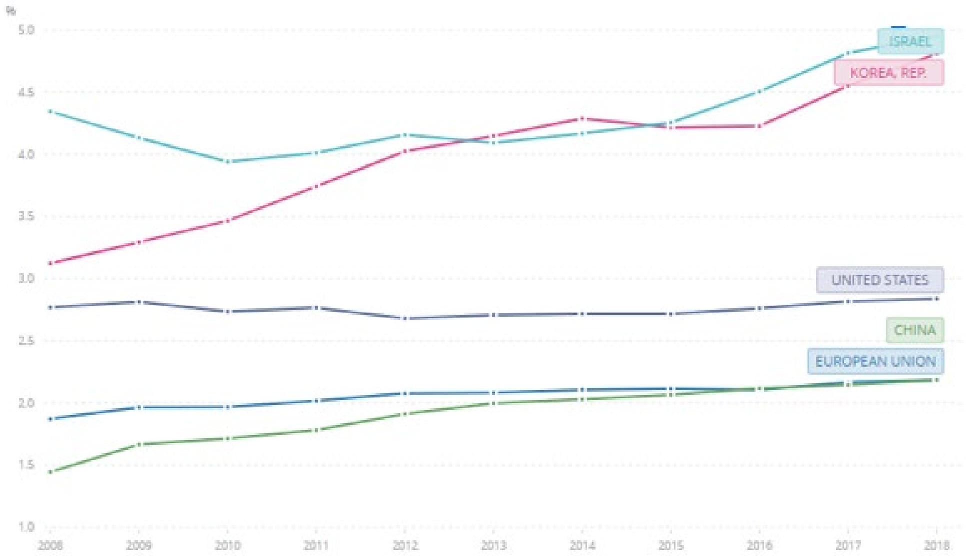
Domestic R&D intensity

Public and private funding for R&D shows the effort of a country or a region to invest in specific technologies or support developments in a certain direction. Currently, the EU spends less on R&D than the USA, Japan, South Korea, and Israel by percentage of GDP (R&D intensity).

The EU remains far from its 2020 target of 3 % in R&D over GDP. According to World Bank data, in 2018, **R&D intensity was 2.18 % for Europe**, which is low when compared to 2.84 % for the US, 3.26 % for Japan, 4.81 % for South Korea and 4.95 % for Israel (see Figure 3.1).[38] In Europe, several countries displayed high R&D intensities surpassing the threshold of 3 % of GDP on R&D expenditure: Sweden (3.34 %), Austria (3.17 %), Germany (3.09) and Denmark (3.06 %).

[38] Research and development expenditure (% of GDP) - European Union | Data (worldbank.org)

Figure 3.1: Evolution of R&D Intensity for major countries in %, 2008-2018

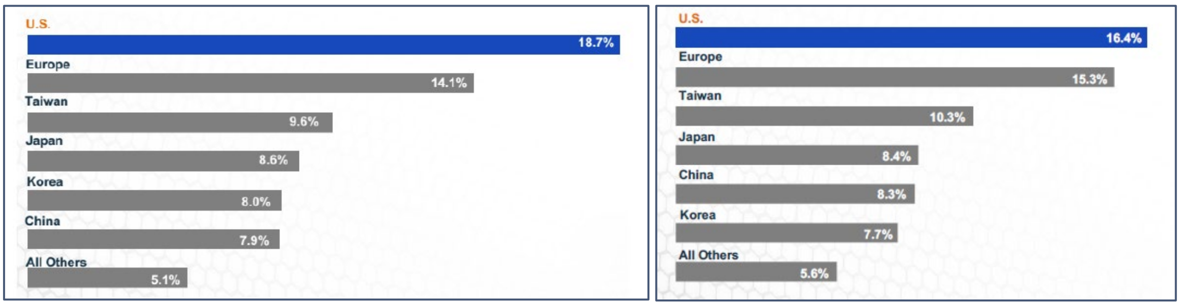


Source: World Bank data, from the Unesco Institute of Statistics database, March 2021

Specific R&D intensity in semi-conductors

In some areas, the EU has **improved its level of R&D intensity**, for example, in the semiconductor industry. The European semiconductor industry has increased its R&D intensity from 14.1 % to 15.3 % and narrowed gaps with the USA between 2017 and 2019 (see Figure 3.2). At the time of writing this report, no updated information allows us to say whether Europe has caught up.

Figure 3.2: Evolution of R&D intensity in 2017 (left) and 2019 (right) in the semi-conductor industry



Source: Semiconductor Industry Association 2020 Factbook.

Public funding programmes related to KETs

In the last decade, the EU has increasingly supported initiatives related to KETs with significant funding through **different instruments that have realized major achievements** so far.

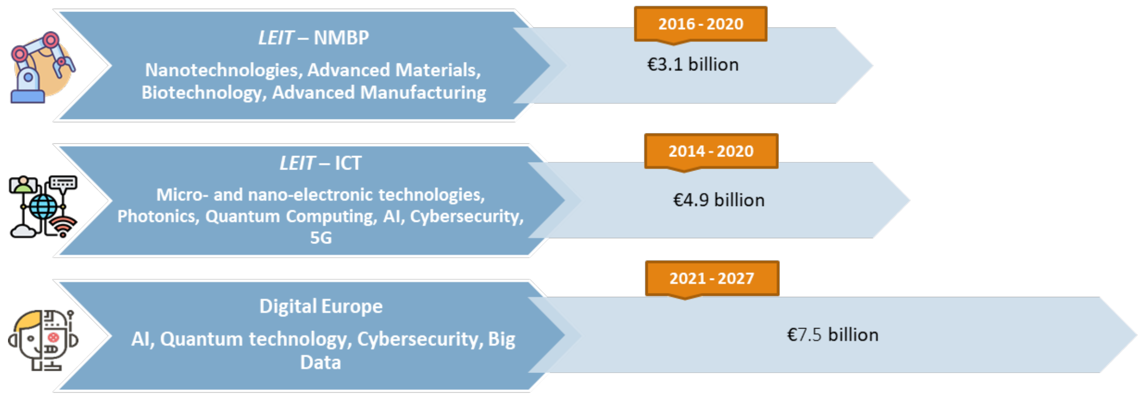
Horizon 2020, the biggest EU Research and Innovation programme, considered KETs as catalysts for boosting Europe's sustainable competitiveness at international level, create jobs and support Member States growth. Hence, the major activities with respect to KETs were included in the **'Leadership in Enabling and Industrial Technologies' (LEIT) programme, part of Horizon 2020**, with a dedicated budget for R&D&I targeting the modernisation of EU manufacturing industries and strengthening the global industrial leadership in manufacturing and environmental sustainability.

- LEIT encompasses in two different work programmes the (1) ICT and (2) Nanotechnologies, Advanced Materials, Advanced Manufacturing and Processing, and Biotechnology (NMPB) in a 6-year time frame (2014-2020). Both work programmes target industrial modernisation and ecosystem growth through the funding of public R&D and infrastructure, innovation hubs and SMEs. As shown in Figure 3.3, **LEIT-ICT** was the first work programme to start its activities. It is funded **with €4.9 billion**[39] **and LEIT-NMPB with €3.1 billion.**[40]

- Some LEIT projects are particularly well-funded. The **largest funding amounts have been dedicated to the ICT sector,** such as in the areas of micro- and nano-electronic technologies (ECSEL joint undertaking on electronic components and systems) and future/next generation internet and 5G (including the 5G PPP) with nearly €800 million each.

In addition, European funding of the digital transformation of industry and the ecosystem is expected to further intensify in the next decade. The **digital Europe programme budget** announced by the European Commission plans to invest €7.5 billion in 2021-2027[41] to further facilitate the wide deployment of digital technologies and complement Horizon Europe.

Figure 3.3: European programmes targeting KETs and associated technologies



Source: Authors' own work, based on the data extracted from the respective programmes.

In Horizon Europe (2021-2027), KETs are identified as one of its nine prioritised interventions as part of the cluster called 'Digital and Industry'.[42] Open innovation is one of the key pillars of **Horizon Europe for which more than €13.5 billion will be dedicated**. The **European Innovation Council (EIC)** was created as the **flagship initiative for SMEs** aiming to support high potential and breakthrough technologies and innovative companies with potential for scaling up. Dedicated budget will be allocated to support potential breakthrough projects and feasibility awards.

Other instruments include the **European Structural and Investment Funds (ESIF) for which KETs are a priority**. More than €22 billion were invested between 2014 and 2020 in research and

39 Horizon 2020 Information and Communication Technologies Work Programmes 2014-2020

40 Horizon 2020 Nanotechnologies, Advanced Materials, Advanced Manufacturing and Processing, and Biotechnology Work Programmes 2014-2020

41 It should be noted that at the moment we started working on this study, this amount was €8.2 billion and was revised downwards in January 2021.

42 The nine intervention areas are Manufacturing technologies, Key digital technologies, Advanced materials, Artificial intelligence and robotics, Next generation internet, Advanced computing and big data, Circular industries, Low carbon and clean industries, Space

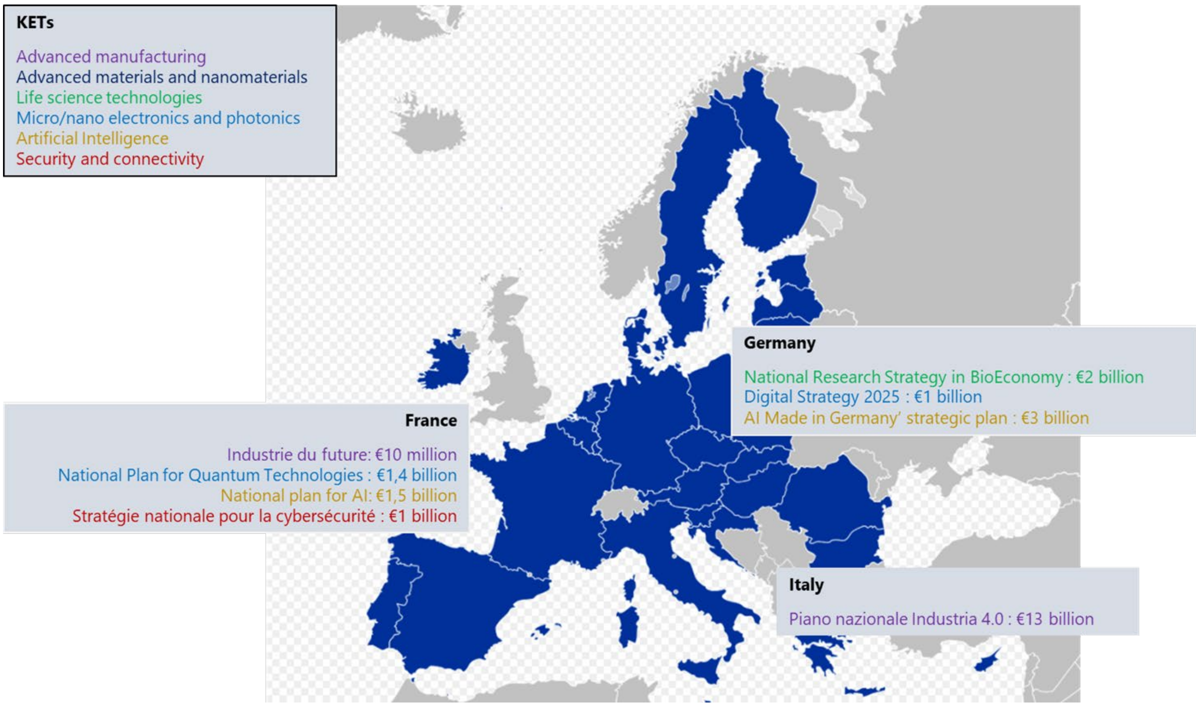
innovation on advanced technologies.[43] Also, a Memorandum of Understanding[44] between the European Commission and the **European Investment Bank** (EIB) signed in 2013 signals KETs as a priority for investments. EIB lending to KETs projects has increased by 10 % per year on average.

Public research programmes funding amount

Based on our own global benchmark gathering all public funding programmes displaying the amount of investment,[45] **the EU will invest approximately €50 billion in total in all KETs in 2015-2027**. More than 90 % of this funding is dedicated to programmes around AI, Quantum Computing and Cybersecurity.

In addition, the Member States that are mostly investing in R&D on KETs are **France, Italy, and Germany** in terms of direct investment and tax reliefs (see Figure 3.4). They are focusing on their sectors of excellence when it comes to directly funding KET initiatives resulting in a concentration of funding at the national level in **advanced manufacturing technologies along with AI, quantum computing, and cybersecurity** gaining ground.

Figure 3.4: Member States public research programmes funding above €1 billion funding in Europe



Source: Authors' own work, based on the data extracted from the respective programmes.

In total, the EU is well positioned regarding research public funding, with **the EU and Member States combined investing approximately €90 billion in total in all KETs.** On the other hand, China is expected to lead the race for manufacturing leadership by 2049 with its ambitious Made in

43 European Structural and Investment Funds (ESIF) data

44 Memorandum of Understanding between the European Commission and the European Investment Bank in respect of their cooperation in Key Enabling Technologies

45 See Table 6.1: Benchmarking of public funding programmes related to the KETs

China 2025 strategy that plans to invest the equivalent of a total of €100 billion to upgrade its industrial base on 10 key industries,[46] which go beyond what the EC has defined as KETs.

Private/Business R&D expenditures

The global technology race intensified with US and Chinese companies sharply increasing their R&D investments between 2017 and 2018, while **European companies lag behind**, not following the same path, as illustrated in Figure 3.5 below. Indeed, the EU Industrial R&D Investment Scoreboard revealed a lower level of R&D expenditure by European companies compared to American or Asian expenditure.[47]

According to the same source, with regard to industries, European companies invest mostly in the automotive sector while US and Asian companies invested mainly in biotechnology and ICT areas:

- The US leads by far in the **biotechnology sector** thanks to a well-developed private sector domain that funds around 68 % of total R&D in pharmaceuticals and food biotechnology. The US private sector invests more than US$33 billion in this field.[48]
- On **ICT production industry**, Asian companies are the top R&D investors. Huawei is highly involved in R&D and is ahead with 13.9 % R&D intensity. In a report presenting the impact of Huawei in Europe,[49] the company claims to be the fifth-largest R&D investor at the global level in 2018-2019 with €12.7 billion. The low private funding level in the EU in ICT were highlighted in the 2020 JRC report and compared to the US, China, Korea and Japan.[50]
- In the area of **AI**, the five US technology giants known as GAFAM[51] are investing heavily as are Chinese companies. Only 9 out of the top 100 global companies leading in AI are European.[52]

In the long term, China and the USA will remain Europe's main competitors due to R&D initiatives pushed by innovative companies in the private sector. Big players and entrepreneurs are a strong support to lead the race in the areas of KETs.

46 New information technology, High-end numerically controlled machine tools and robots, Aerospace equipment, Ocean engineering equipment and high-end vessels, High-end rail transportation equipment, Energy-saving cars and new energy cars, Electrical equipment, Farming machines, New materials, such as polymers, Biomedicine and high-end medical equipment.

47 2019 EU Industrial R&D Investment Scoreboard European Commission, JRC/DG RTD

48 Biotechnologies activities in the world, p 58

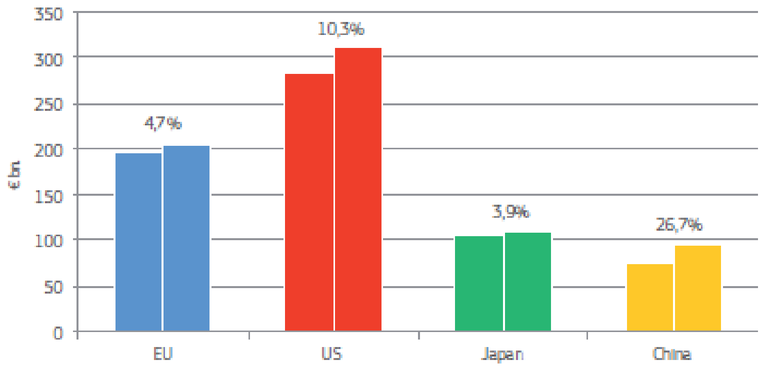
49 The economic impact of Huawei in Europe, Oxford Economics, November 2020

50 THE 2020 PREDICT REPORT, Key Facts Report, An Analysis of ICT R&D in the EU and Beyond

51 GAFAM stands for Google, Amazon, Apple, Facebook and Microsoft and are the five largest digital companies in terms of market capitalisation.

52 AI research ranking by Gleb Chuvpilo

Figure 3.5: R&D investment growth of the top 2 500 companies, in %, 2017-2018



Source: 2019 EU Industrial R&D Investment Scoreboard European Commission, JRC/DG RTD

3.2.2. Education & skills

Education is a key ingredient in technological sovereignty. It is essential for the development and preservation of skills required to master KETs, as already identified as one of the main challenges in section 2.2.1. As confirmed in several interviews, Europe must ensure that it has the skills for current and future workers, as well as having the required number of qualified people to work in KETs. Thus, this subsection focuses on STEM (Science, Technology, Engineering, and Mathematics) skills, subjects that are in line with KETs.

Number of STEM graduates

Looking forward, advancements in academia are a crucial factor to develop a more capable workforce for tomorrow. The skills gap will play a vital role in the race for leadership in KETs. Therefore, countries are stimulating STEM education and research programmes with more funding. The development of STEM education does not however guarantee that graduates will stay in the country after obtaining a degree. This **risk of brain drain should therefore be considered and certain conditions should be created to retain tech graduates within the EU economy**.

In terms of STEM, Chapter 2 already mentioned a **deficit of skills** compared to other nations, mainly the USA. According to multiple sources (although lacking in relevant and updated figures), there is a deficit of graduates to work in advanced technologies in Europe.

On the other hand, EU27 accounts for around 1 million STEM graduates (based on Eurostat data) which is comparable to China and the USA.[53] According to the World Economic Forum,[54] China had 4.7 million STEM graduates in 2016 and there were 568,000 in the USA. However, these figures are hard to compare since the aggregated nation-level data is not available and every country and research organization uses different methodology to calculate the number of STEM graduates.

Nevertheless, STEM education remains a popular choice for European students. According to the UNESCO Institute for Statistics,[55] **3 European countries (Germany, France and Spain) were in the global top 15 countries per share of graduates who chose STEM degrees in 2018 with over 20 % of total graduates.** At the same time, the US were out of this list with only 18 % of graduates in STEM. However, UNESCO published no data for China. But by taking into account the figure from

53 Eurostat dataset Graduates in tertiary education, 2021

54 The country with the most STEM graduates, World Economic Forum, 2017

55 Data from UNESCO Institute for Statistics

the World Economic Forum, the share of graduates with STEM degrees could be estimated at more than 50 % which would make China by far the global leader.

Many current and future defence systems will depend on high tech advancements in cybersecurity, AI, quantum computing and even nanotechnology. This is why Europe and its **Member States should undertake an effort to develop these skills though a relevant education policy.** Details on policy options can be found in section 4.3.3 on the development of necessary skills.

Specifically, on ICT, an EC study on the Academic Offer of Advanced Digital Skills provides evidence on the availability of educational programmes in the EU27 (number of bachelor & master programmes and short courses) with regards to specific advanced digital skills in the international context. [56] In **the field of AI, the EU offers a good range of educational possibilities** (especially for masters and business-oriented short courses), slightly behind the USA, while in cybersecurity the EU has a lower number of degrees offered.

However, in the context of supporting the development of the necessary skills for mastering the KETs in Europe, the attention should be paid that resources are not automaticaly diverted from non-STEM subjects towards eduction in STEM. In addition to producing more STEM-educated workers in Europe, steps could be taken to attract more of those workers to Europe or to prevent the brain drain and retain them.

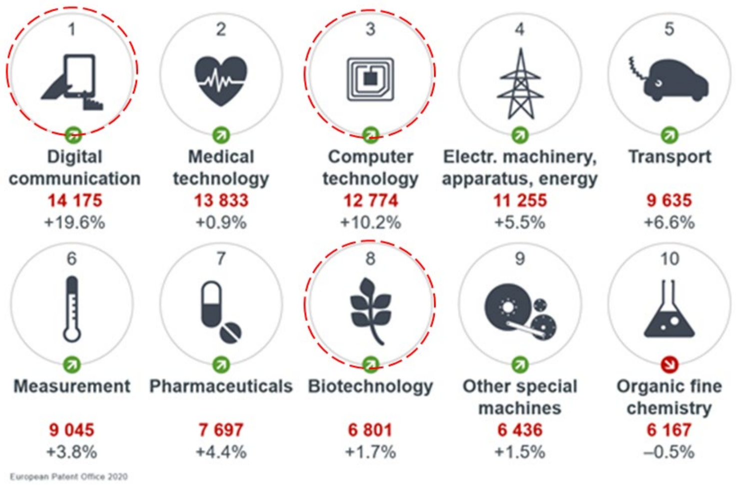
3.2.3. Innovation

Patents encourage the development and protection of innovations and new technologies in every field. Patent development remains a reflection of inventors' and businesses' capacity to innovate. This subsection presents Europe performance in patenting compared to other countries as well as the capacity to collaborate with other countries in invention.

Share in global patenting

The patent applications filed with the European Patent Office (EPO) in 2019 show digital communication, computer technology and biotechnology as major sectors (see Figure 3.6).[57]

Figure 3.6: Technical sectors with the most patent applications 2019



Source: European Patent Office, Annual report statistics, 2019

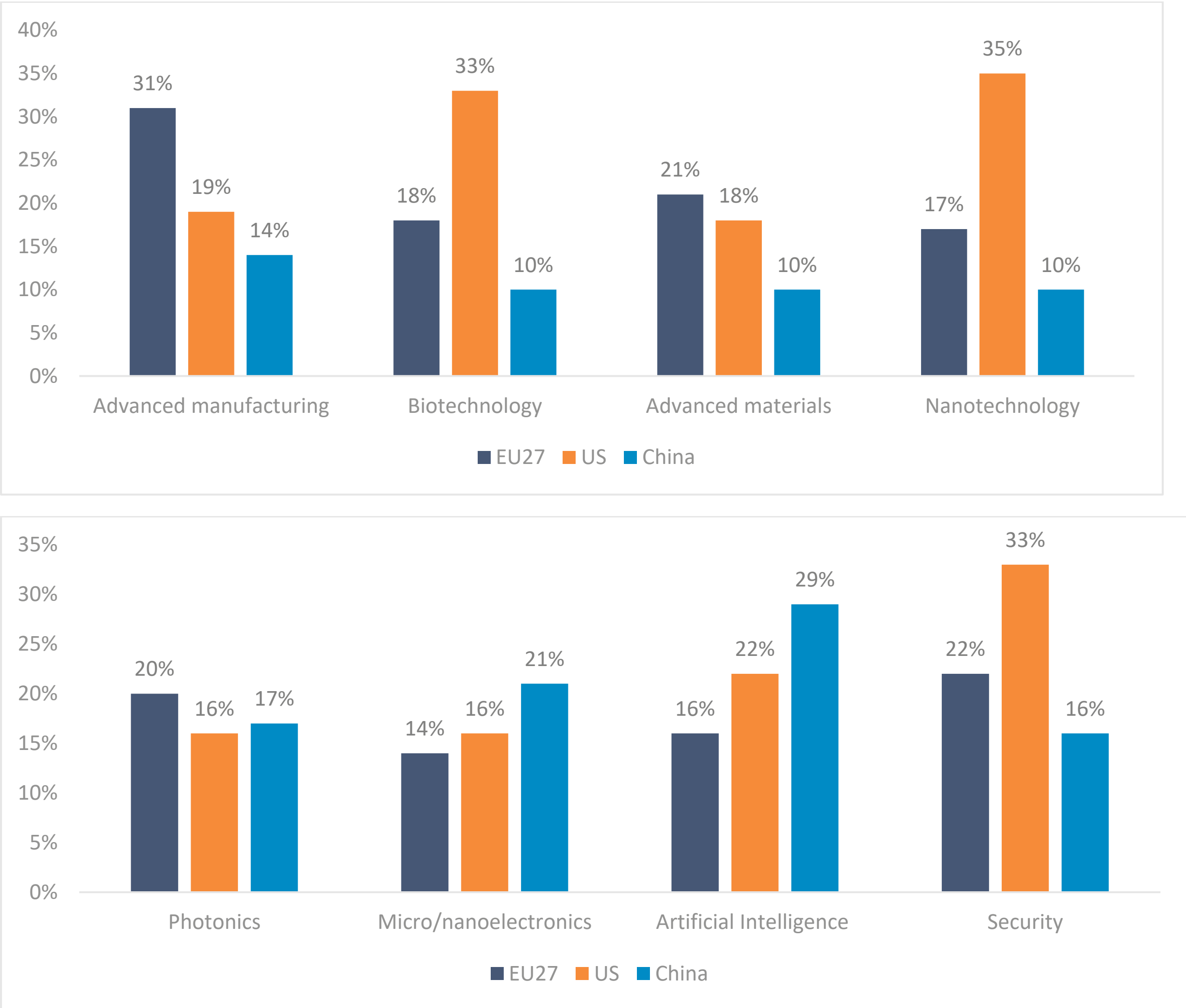
[56] Academic Offer of Advanced Digital Skills in 2019-20. International Comparison, JRC technical report, 2020

[57] Digitalisation-triggers-patenting-growth, European Patent Office, annual report statistics 2019

Looking at the number of patents in the areas of KETs, **the EU performs well in patenting in the different fields**. The EU notably leads in specific areas like advanced manufacturing according to the EPO. In other areas, Europe stands second behind the USA, Japan or China, depending on the fields (see Figure 3.7):

- In the field of digital communication, the Chinese network equipment provider Huawei is listed as the leading patent applicant in 2019 globally, ahead of the European manufacturers Ericsson and Nokia;
- Overall, US companies lead in computer technology;
- For biotechnology patents, the USA is also leading, with European applicants not far behind. The USA is the source of new medicines about three times more often than the EU and about nine times more often than China.

Figure 3.7: Relative share of global patenting per KET, 2018



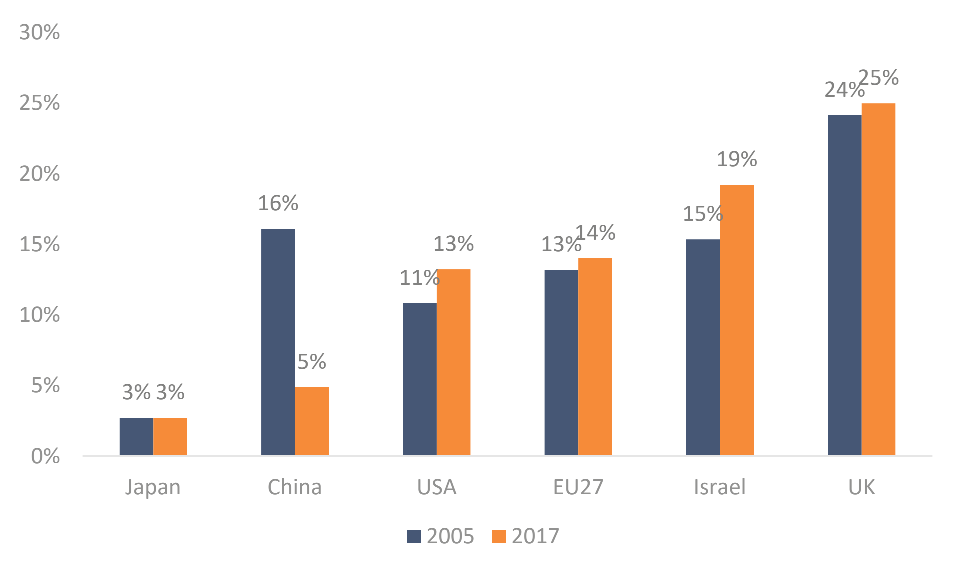
Source : IDATE from Advanced Technologies for Industry (ATI) Data Dashboard, Country indicators – European Commission

Share of international co-inventions

International collaboration and co-invention are also key drivers for quality of research, innovation and standards development, as highlighted by some of our interviewees. In order to measure this collaboration in research, the ATI project has defined the international co-inventions indicator as a percentage of patents involving inventors from different regions.

Europe remains more involved in this process than China and the USA, particularly due to the high involvement of small European countries like Luxembourg or Malta. However, the share of international co-patents of EU countries has not grown over the last ten years (see Figure 3.8).

Figure 3.8: Share of international co-inventions - non-KET-specific



Source: IDATE from Advanced Technologies for Industry (ATI) Data Dashboard, Country indicators – European Commission

3.2.4. Entrepreneurship

Entrepreneurship, considered as the capacity to create start-ups, spin-offs or businesses, is a key aspect of technological sovereignty. This subsection assesses how Europe performs in terms of the number of start-ups.

Number of start-ups and scaleups

Even though the European start-up ecosystem has developed significantly over the past years, the EU is still far behind the USA in terms of the total number of start-ups. According to data from Start-up Ranking,[58] over 70 % of all start-ups in the world are currently concentrated in the USA, while the EU represents only 7 %.

However, Europe has been advancing in the development of a competitive start-up ecosystem: the number of promising technology-oriented start-ups in Europe has been growing. As an example, the AI landscape in the EU numbers around 500 start-ups mainly from France, Germany and Sweden.[59] European start-ups benefit from state support. For example, in 2019 Bpifrance invested €368 million in French companies developing AI.[60] However, few European start-ups that develop AI-based solutions are worth more than one billion USD while the vast majority of unicorn[61] start-ups are from the USA.[62]

58 Start-up ranking : Ranking of start-ups by country

59 European AI Startup Landscape

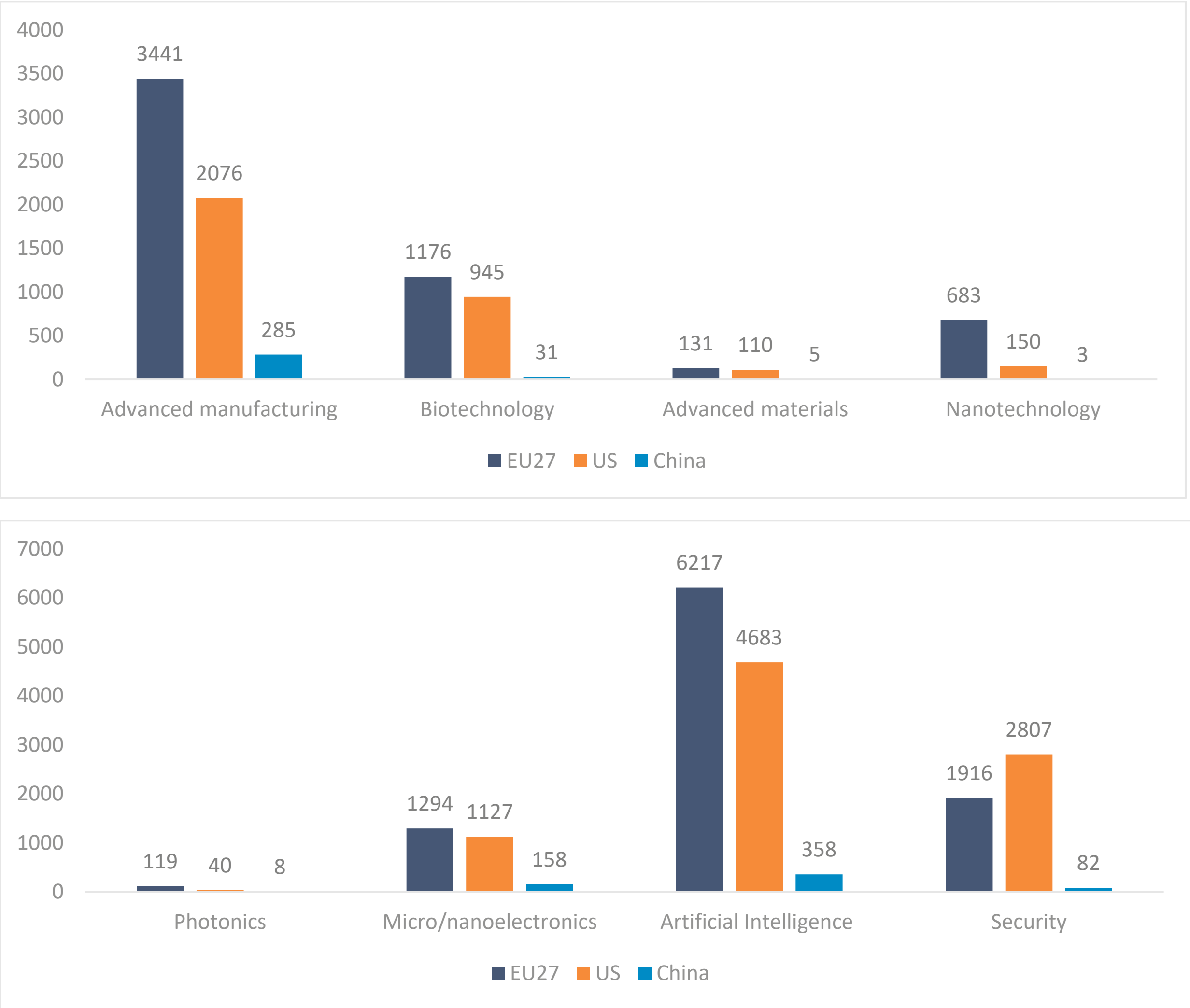
60 Bpifrance Le Hub,

61 Startup company valued at over $1 billion.

62 The Complete List Of Unicorn Companies

More specifically, on the KETs, the ATI project monitored the number of Venture Capital-backed start-ups over the decade between 2009 and 2019. For the 6 KETs, the USA is ahead of the EU by number of start-ups and scale-ups.[63] However, on specific KET, **the EU is performing well in several KETs: leading alongside the USA on advanced manufacturing, largely leading in the field of nanotechnology**. On the other hand, for ICT KETs, the EU 27 remains second to the USA (see Figure 3.9).

Figure 3.9: Number of start-ups and scale-ups in 2019



Source: IDATE from Advanced Technologies for Industry (ATI) Data Dashboard, Country indicators – European Commission

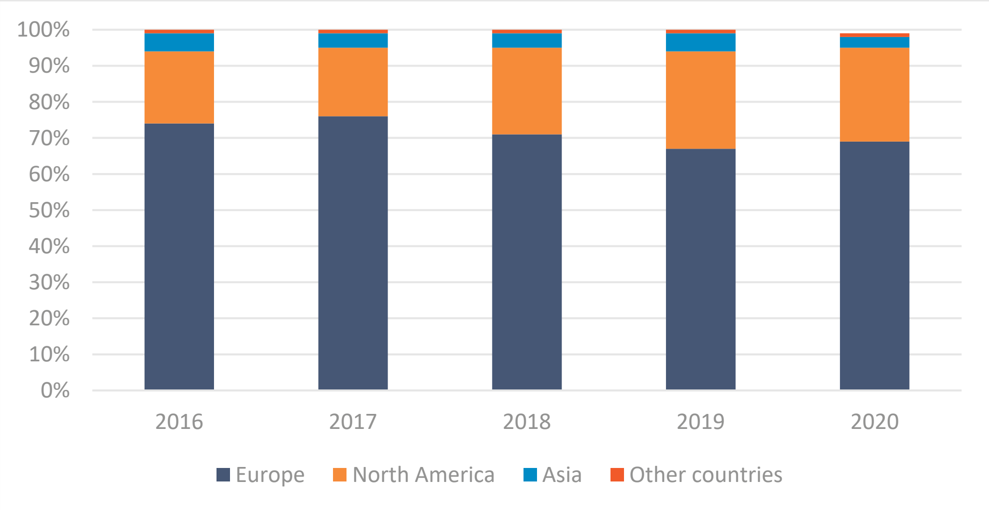
Fate of European start-ups in KETs

While the majority of European tech start-ups backed with venture capital (VC) remain acquired by European companies, **the share of companies founded by European entrepreneurs and purchased by international companies has increased over the last five years** from 26 % to 31 % as shown in Figure 3.10 below.

63 AT startups and scaleups from KET observatory/ATI project

Furthermore, in 2020, **US companies were behind seven out of the ten largest VC-backed acquisitions of European tech start-ups** (6 out of 10 in 2019). For example, the cloud software company Veeam was acquired in 2020 by the US private equity fund Insight Partners for US$5 billion which represented the largest exit (excluding IPOs) for a European VC-backed tech start-up that year. The EU and its Member States should therefore not only stimulate start-up launches but also introduce policy to make their acquisition more attractive for European companies so that these start-ups stay inside the EU economy.

Figure 3.10: Share of M&A exits of European VC-backed companies by buyer region, 2013-2018



Source: IDATE from The State of European Tech 2020, Atomico

3.2.5. Industrial ecosystem

Technological sovereignty and industrial leadership stand in a mutual relationship. This section presents the current competitive position of Europe's industrial players in the different KETs, particularly in comparison with the USA and China. Industry sectors have been associated to each KET in order to assess the EU position.

Industrial leaders ranking

The table below summarises the leading players for the industry sectors related to each KET and provides an assessment of the EU position. It shows that generally **Europe has no leadership in any KET.** All the global leaders in technologies such as industrial engineering and petrochemicals are from China while the other sectors such as biotech, semiconductors, digital services and cybersecurity are dominated by US companies. Despite efforts to control the handling of personal data, Europe is absent from the cloud market as European enterprises and institutions depend on American suppliers to protect their critical systems security. The USA largely dominates the cloud market thanks to Microsoft, Amazon, Google and IBM that jointly hold 70 % of the IaaS, a key subsegment cloud market.[64]

For the majority of these industry sectors, only a **few companies in each of the global top 10 come from European countries**. In some specific industries, companies from Europe are often present among the world's largest players. In particular, **Europe is strong in industrial engineering** where its secure position is due to very large key players in this field, especially from Germany. For instance,

[64] Worldwide Iaas Public Cloud Services Market, Gartner, 2019

Siemens' recent innovation enables companies to create digital twin models of envisioned advance manufacturing plants. Another sector where **European companies are among the leaders remains telecom equipment manufacturing**.[65] In particular, the two European players, Nokia and Ericsson, have been gaining ground in the 5G deployment race due to sanctions imposed by the US on Huawei.[66] Finally, Europe's strong position in cybersecurity is maintained by the French multinationals (Atos and Avast) which appear right after the American leaders in the ranking of top 10 cybersecurity players.

Besides, as already mentioned in section 2, the **EU is not rich in raw materials,** thus affecting its competitive position in several industries such as advanced materials. In addition, a competitive chemicals sector is crucial for Europe as 95 % of all manufactured goods in the EU make at least some use of chemicals, including electronics, furniture, appliances, textiles, and many more.[67] Another example is the biotech sector where companies depend significantly on suppliers of lipids, a critical component in vaccine production. The **lipid market is largely represented by US companies**. On top of that, **large tech US companies have access to much more data compared to European players**, creating another significant advantage for the US in development of technologies and applications requiring massive data inputs such as AI.

Specific policy options addressing the lack of raw materials and resources can be found in Section 4.3.2.

Table 3.2: Summary of industrial leadership per KET and EU position

KET	Industry sectors	EU position	Industry leadership and structure
Advanced manufacturing	Industrial engineering & Robotics	Challenger	○ Global industrial engineering market led by Chinese companies ○ Industrial robot manufacturer market largely dominated by Japanese companies and European companies. ○ Presence of EU companies in the top 10 markets (Vinci, ABB)
Advanced Materials and nanomaterials	Petrochemicals & carbon fibre	Challenger	○ Half of the world's largest companies in the sector are from the Asia-Pacific region (China and Japan). ○ Presence of EU companies in the top 10 (BASF, SGL Carbon)
Life science technologies	Pharmaceuticals & biotech	Laggard	○ Largely dominated by the US companies ○ Presence of few European companies in the top 10
Micro/Nano electronics and photonics	Semiconductors & photonics	Laggard	○ Semiconductors market dominated by the USA and South Korea. European players struggled to climb in the top 10 ○ Photonics market, highly fragmented, dominated by Asian companies

65 Telecommunication Equipment Makers in H1 2020, Dell'Oro Group

66 Huawei's Rivals Are Already Filling A $27 Billion Hole Left By US Sanctions, Forbes

67 Economic Outlook 2021 for the European chemical industry

			○ Europe accounts for active photonics companies mainly SMEs
Artificial intelligence	Digital services & software	Laggard	○ Market largely dominated by big tech US companies
Security & connectivity technologies	Cybersecurity & Telecom equipment	Challenger	○ Cybersecurity market dominated by US and Chinese players. Presence of few EU players (Avast, F-Secure) ○ Telecom equipment market led by the Chinese maker Huawei followed by 2 European major players (Nokia and Ericsson)

Source: Authors' own work.

SMEs in the KETs

In Europe, SMEs play a critical role in the economy: in 2018, **SMEs accounted for over 99 % of all European non-financial companies and employed 70 % of all the workforce in Europe.**[68] However, **European SMEs appear to be less innovative compared to large companies**. According to the Annual Report on European SMEs,[69] around 38 % of all SMEs in the EU in the period 2014-2016 (the latest data available) reported at least one product or process innovation, against 68 % of large companies. The adoption of advanced technologies is also lower for SMEs. In 2018, only slightly less than 10 % of European SMEs adopted big data and around 25 % used cloud computing (compared to over 30 % and almost 60 % of large companies respectively).[70]

In terms of KET, Europe accounts for **many innovative SMEs in specific sectors such as photonics** where almost all of the 5000 European companies are small organisations. At the same time, only a small share of SMEs in Europe (less than 25 % according to the KET4CleanProduction report[71]) are aware of how KETs can improve their business processes. Section 4.3.1 addresses policy options to tackle this issue.

3.3. Assessment of Europe's technological sovereignty

Based on the analysis of the key ingredients required for technological sovereignty, we present the global assessment of Europe, especially compared to the USA and China. Table 3.3 below summarises for each indicator how EU27 is positioned globally or per KET.

Europe still lags behind in terms of R&D funding. Both **public spending on research and R&D by private companies are on average lower in Europe than in the USA and in China**. However, R&D on some of the KETs is highly supported by public initiatives of European countries. For example, large and dedicated national funding initiatives driven by France and Italy in advanced manufacturing and research in artificial intelligence are well-funded and supported through dedicated European and national programmes. On the contrary, the support of life-science technologies is very low, both at the European and Member States' level.

68 Number of small and medium-sized enterprises (SMEs) in the European Union in 2018, by size, Statista, February 2021

69 Annual Report on European SMEs 2018/2019, European Commission, November 2019

70 Supporting specialised skills development: Big Data, Internet of Things and Cybersecurity for SMEs, Interim Report, March 2019

71 KET4CleanProduction – Report on SME needs analysis outcomes and framework conditions, 2019

In education, which plays a critical role in the technological leadership race, **European countries cannot compete individually with the global leaders by overall number of STEM students**. However, three EU Member States are in the top-15 by the share of graduates with STEM degrees.[72]

Furthermore, **from an industrial perspective, Europe can hardly compete with its main rivals (USA and China), especially in the fields of micro/nano-electronics and artificial intelligence**. Even though some of the largest European companies appear among the world's top players in industrial engineering or advanced materials, the leading positions are usually held by American technological giants or Chinese groups.

Nevertheless, Europe has been fairly **strong in developing a competitive start-up ecosystem**. But the share of new companies founded by Europeans purchased by large international players has increased over the last five years. And, the largest acquisitions of European start-ups are often backed by US funds and companies.

In addition, as cited in the entrepreneurship sub-section, the share of unicorns, start-ups worth over a billion USD, is small in Europe compared to the USA and China. Lastly, Europe has shown its **capacity to innovate through its intermediate position in delivering patenting on KETs** especially in the advanced manufacturing field. Europe also has an advantage over the USA and China in international technological collaboration. With the overall significant amount of patents issued, Europe has a higher share of international co-inventions than either of these countries.

Finally, in line with the definition of technological sovereignty and based on the indicators provided in the study, Europe is fairly weak in developing technologies: despite good intentions for investing, the level remains lower than the USA and China. The same observation applies to providing technologies with a great number of VC-backed start-ups in the KETs but no leadership position. Protecting technologies is where Europe is strong with a high capacity to deliver innovation through patents and co-invention. Finally, Europe is very weak in retaining technologies due to a lack of skills and qualified people to work in KETs.

72 UNESCO Institute for Statistics

Table 3.3: Technological sovereignty assessment globally and per KET

Indicators	Advanced Manufacturing	Advanced Materials and Nanotechnologies	Life-science technologies	Micro/nano-electronics and photonics	AI	Security and connectivity technologies
Domestic R&D intensity	Low					
Amount of public research programmes funding	Medium					
Business/private R&D expenditures	Low					
Number of STEM graduates	Low					
Relative share in global patenting	High	Medium	Medium	Medium	Medium	Medium
Number of international co-inventions	High					
Number of start-ups	High	High	High	Medium	High	Medium
Industrial leaders ranking	Medium	Medium	Low	Low	Low	Medium

Source: Authors' own work

4. Policy options for Europe's technological sovereignty

In this chapter, we provide an assessment of selected existing policies in relation to their efficacy in supporting KETs and of policy gaps and challenges preventing the effective development and implementation of policies. Based on this assessment and on the analysis in Chapters 2 and 3, specific suggestions for policy options are outlined to address the identified challenges and enhance the technological sovereignty of the EU.

As defined in Chapter 1, European technological sovereignty is the ability for Europe to develop, provide, protect and retain critical technologies required for the welfare of European citizens and prosperity of businesses, and the ability to act and decide independently in a globalised environment. Policy options discussed in the following sections target these economic, technological or political aspects of technological sovereignty.

4.1. Assessment of existing EU policies

An **abundance of policies** contribute to the EU's technological sovereignty, such as R&D&I policy, various funding measures, procurement policy, intellectual property protection, state aid, competition, investment and trade policy. Their impact on KETs differs, with some of the measures having a more direct impact (e.g. R&D&I policy, intellectual property rights law) than others (e.g. competition law). Nevertheless, an optimal combination of all measures should be sought to achieve the best possible environment for KETs.

4.1.1. General assessment of the existing EU policies


Regulatory fragmentation

In a more general assessment of relevant EU policies, stakeholders and experts deplore the **lack of joint action and coordination** between different levels of governance and sometimes different policies. Our interviewees mentioned the lack of coordination in many contexts, from funding programmes to the development of R&D&I policies.[73] There is a need to reinforce a coordinated approach to R&D&I by addressing the erratic focus on strategic challenges and the suboptimal link between R&D&I and policy-making.[74] However, there has been a positive change in this competitive mindset towards more cooperation. The interviewees note, for example, that Member States encourage researchers to apply for EU-level funding instead of promoting national funding, and policies such as the European research area (ERA) provide a framework for R&D&I cooperation across the EU.

In some of the important aspects fostering new technologies, the EU has adopted remarkable **forward-looking policies** or is currently working on them. The EU is clearly keeping pace with technological development and is also framing technological developments as witnessed by the adoption of such important legal instruments as the General Data Protection Regulation (GDPR),[75]

[73] Pickard S, Learning from COVID-19: A catalyst for European R&D policy and practice? Science Business of 20.04.2020; Rubio E, Zuleeg F, Magdalinski E, Pellerin-Carlin T, Pilati M and Ständer P, Mainstreaming Innovation Funding in the EU Budget, Study for the European Parliament's Committee on Budgets, 2019.

[74] European Commission, Commission Staff Working Document. Impact assessment – Proposal for a Regulation of the European Parliament and of The Council establishing Horizon Europe, SWD(2018) 307 final.

[75] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC, OJ L 119 of 4.5.2016.

the Regulation on the Free Flow of Non-personal Data,[76] the Open Data Directive,[77] the European Electronic Communications Code[78], the Cybersecurity Act[79] and many others, or by the proposed AI act.[80] For some of the KETs, the EU is adopting or discussing pioneering policies, like the 2008 Code of conduct for nanotechnologies,[81] the various codes of conduct on energy efficiency for connectivity technologies[82] or more recently the Ethics Guidelines for Trustworthy Artificial Intelligence, by the High-Level Expert Group on AI.[83] Finally, the EU has also taken action in non-technology related areas such as access to raw materials, most recently through the action plan on critical raw materials.[84]

While there is already a rich policy and legal framework in place (including for some individual KETs, e.g. nanomaterials), interviewees indicate that a **more consistent and effective implementation and application** of relevant measures would achieve better outcomes for Europe's technological sovereignty. For instance, most Member States are delayed in their transposition of the European Electronic Communications Code,[85] which contains important rules on infrastructure deployment and spectrum management and is therefore crucial for the investment in and introduction of 5G in Europe. Another example is innovation procurement.[86] Interviewees were positive about this as an instrument for innovation, but remarked that implementation across the EU was inconsistent.

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76 Regulation (EU) 2018/1807 of the European Parliament and of the Council of 14 November 2018 on a framework for the free flow of non-personal data in the European Union, OJ L 303 of 28.11.2018.

77 Directive (EU) 2019/1024 of the European Parliament and of the Council of 20 June 2019 on open data and the re-use of public sector information, OJ L 172 of 26.6.2019.

78 Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 establishing the European Electronic Communications Code (Recast), OJ L 321 of 17.12.2018.

79 Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013, OJ L 151 of 7.6.2019.

80 Proposal for a Regulation of the European Parliament and of the Council laying down harmonised rules on Artificial Intelligence (Artificial Intelligence Act) and amending certain union legislative acts, COM(2021) 206 final as of 21 April 2021

81 European Commission, Commission recommendation on a Code of Conduct for Responsible Nanosciences and Nanotechnologies Research, COM(2008) 424 of 7 February 2008.

82 For example, the codes of conduct for ICT (2000) and data centres (2008). For more information see: EU Science Hub. Code of Conduct for ICT.

83 The guidelines and supporting studies can be downloaded from: https://ec.europa.eu/digital-single-market/en/news/ethics-guidelines-trustworthy-ai.

84 European Commission. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. COM(2020) 474 of 03.09.2020.

85 See the overview of the transposition efforts at: https://www.clintworldsolutions.com/cw/2020/08/26/eu-member-states-status-of-eecc-transposition-into-national-law/news/#page-content.

86 In its Guidance on Innovation Procurement, the European Commission defines 'innovation procurement' as any procurement that has one or both of the following aspects: 1) buying the process of innovation – research and development services – with (partial) outcomes; 2) buying the outcomes of innovation created of others.

4.1.2. Shortcomings of existing EU policies

The **lack of a true single market** continues to be one of the most serious shortcomings of EU-level policies. While the degree of integration has increased thanks to EU-level strategies and other joint actions in all or some of the individual KETs,[87] the regulatory landscape remains fragmented and national approaches differ.[88] Regulatory fragmentation may be exacerbated by the difficulties of comprehending and navigating the EU's multilevel governance structures. In relation to R&D&I, there are at least four levels – European, national, regional and local – that are involved, and there is a lack of transparency and understanding of what each level is responsible for. This is particularly a problem for SMEs. Moreover, the EU supports internally those regions that lag behind but does not always succeed in promoting European industry or champions globally. Therefore, by working towards European rather than national champions in industry, the EU would send a strong signal outside the EU.[89]

The stakeholders interviewed felt that **support for start-ups and commercialisation of R&D is not sufficient**. One of the main problems is the lack of available public and private investment, especially compared to the USA and China. In addition, precommercial procurement and early admission to the market has not been much of a priority. Limited scale-up of innovative SMEs at EU level and lack of venture capital was also one of the key challenges in the Horizon Europe impact assessment.[90] However, a positive turn is expected in both cases: the new financial instruments envisage greater support for commercialisation (see Box 4.1) and the Council has adopted conclusions to facilitate experimentation, piloting and testing.[91]

Box 4.1: New approaches to funding in the new financial instruments of the EU

> **Horizon Europe** (€100 billion) contains a specific pillar 3 'Innovative Europe' devoted to the support of innovation. European Innovation Council will provide Pathfinder (early technology to pre-commercial) and Accelerator (pre-commercial to market and scale-up) grants to help innovators create markets, leverage private finance and grow. Some 70 % of the budget is earmarked for SMEs. The **digital Europe programme (DEP)** – €7.5 billion) will support further commercialisation and deployment of technologies by building up strategic digital capacities and deploy digital technologies. It targets AI, supercomputing, cybersecurity and digital skills.

SMEs and start-ups have great potential for innovation, but many interviewees felt that laws and regulations **fail to promote** this potential. Digital innovation hubs (DIHs), cluster organisations, and research and technology organisations can help with some of the shortcomings. However, as mentioned, small companies have difficulty navigating complex regulations, dealing with red tape, and do not have the lobbying power of the big companies. One interviewee noted that the current

87 See in particular European Commission, A European Strategy for Micro- and Nanoelectronic Components and Systems, COM(2013) 298 of 23.5.2013; European Commission, Artificial intelligence for Europe, COM(2018) 237 of 25.4.2018, European Parliament and the Council, The EU's Cybersecurity Strategy for the Digital Decade, JOIN(2020) 18 of 16.12.2020; European Commission, A New Industrial Strategy for Europe, COM(2020).

88 High Level Expert Group on Key Enabling Technologies (HLG-KET), Key Enabling Technologies: Time to act, 2016; Gouardères F, Innovation Policy, Fact Sheets on the European Union, European Parliament, 2020.

89 See the discussion on changing competition rules to support European champions in the aftermath of the prohibition of the Siemens-Alstom merger in Efstathiou K, The Alstom-Siemens merger and the need for European champions, Brueghel blog of 11.03. 2019; also Szczepański M and Zachariadis I, EU industrial policy at the crossroads: Current state of affairs, challenges and way forward, EPRS in-depth analysis, 2019, pp. 16-17.

90 European Commission, Commission Staff Working Document. Impact assessment – Proposal for a Regulation of the European Parliament and of The Council establishing Horizon Europe, SWD(2018) 307 final.

91 Council of the EU, Council Conclusions on Regulatory sandboxes and experimentation clauses as tools for an innovation-friendly, future-proof and resilient regulatory framework that masters disruptive challenges in the digital age of 16.11.2020.

legal framework fails to curb the market power of large companies, although compared to third countries such as the USA, market power is less of an issue in the EU.[92]

Public procurement policies are known as an effective demand-side instrument to support R&D&I efforts,[93] especially by SMEs and start-ups.[94] Several interviewees criticised the **lack of procurement strategy to support KETs** and the fact that implementation of the 2014 Procurement Directive[95] has not yet resulted in a simplified, more results- and innovation-oriented procurement, due to inconsistent transposition and application by Member States.[96]

The EU has created a number of policy initiatives to support **digitisation and digital skills**[97] as well as **STEM skills**[98] across the economy. While these are crucial in providing a basis for many KETs, some interviewees felt that further and more targeted efforts were necessary because SMEs and public sectors are still lagging behind.[99] Results from the International Digital Economy and Society Index (I-DESI) highlight that while the top-performing EU countries outperform most third countries in digital skills (the exception being the USA), on average the EU is lagging behind third countries in areas such as basic software coding skills. However, the EU performs well in its high number of ICT graduates.[100] Still, the 2030 Digital Compass notes that the EU growth rate in ICT specialists is too slow to cover future demand and over 70 % of businesses report the lack of staff with adequate digital skills as an obstacle to investment.[101]

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92 A study by the ECB finds that the levels of concentration and market power of big companies on the EU market remain stable and lower than in other jurisdictions. See Cavalleri MC et al., Concentration, market power and dynamism in the euro area, ECB Working Paper Series No 2253, 2019.

93 For the economic explanation, see Edler J, Demand-Based Innovation Policy, Chapter 12, in Smits R E, Kuhlmann S and Shapira P (eds.), *The Theory and Practice of Innovation Policy*, Edward Elgar Publishing, 2010.

94 European Commission, Public Procurement as a Driver of Innovation in SMEs and Public Services, 2014.

95 Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on public procurement and repealing Directive 2004/18/EC, OJ L 94 of 28.3.2014.

96 For details see Valenza A, Alessandrini M, Negrila P and Celotti P, Assessing the implementation of the 2014 Directives on public procurement: challenges and opportunities at regional and local level. Study for the Committee of the Regions, 2019.

97 The initiatives supported by the EU and the Digital Skills and Jobs Coalition at the EU and national levels are, for example, Digital Opportunity traineeships, European Digital Skills Awards, and Digital Champions Expert Group. For digitising industry, the EU has a range of initiatives, many of them targeting specific industry sectors.

98 Such initiatives include, for example, the EU STEM Coalition, an EU wide network supporting STEM education, and the STEM Alliance, a PPP bringing together companies and Ministries of Education on STEM education.

99 Some industry sectors are particularly slow in adopting technologies, in particular construction, infrastructure and manufacturing sectors. See EIB, Who is prepared for the new digital age? - Evidence from the EIB Investment Survey, 2020.

100 Tech4i2 (2021) 2020 International Digital Economy and Society Index - SMART 2019/0087, Luxembourg, Publications Office of the European Union.

101 The Digital Compass was released in 2021 and sets out the vision for making 2030 a decade of empowering citizens and businesses through a digitalised economy. One of its key priorities is skills. For more information, see: European Commission, 2030 Digital Compass: the European way for the Digital Decade, 2021.

Box 4.2: Diversity in STEM, ICT and R&D&I

The Digital Compass also notes a severe gender imbalance in ICT and STEM. While not directly relevant to KETs, **gender equality** is an important goal in the EU R&D&I policy based on the overarching Gender Equality Strategy for 2020-2025. Specific objectives for gender equality in R&D are set in the European Research Area framework and followed up by national action plans. As noted by the She Figures study and ERA Progress report, progress has been slow and implementation across Member States uneven. Women are still underrepresented in all areas of science, technology, engineering, and mathematics (STEM) and top academic positions. Meanwhile, the **participation of ethnic minorities** in R&D&I remains unaddressed to this day in policy.

Many stakeholders feel that the EU's **standardisation and certification** (or admission to the market) **policy is not fit** to support the development and deployment of new technologies. The procedural side of standards development is criticised for being too slow and politicised in the international context. Slow procedures may discourage countries from seeking common solutions and instead encourage national solo efforts, as shown by the example of Finland developing an IoT cybersecurity certification label ahead of a European certification scheme.[102] Some interviewees mentioned that admission to the market of Covid-19 vaccines demonstrated that things can go much faster and more efficiently and that this lesson could be adopted for KETs.[103] An expert panel at the EU Industry Days voiced a similar sentiment when arguing that Covid-19 showed that Europe can actually act fast in turning innovation into products.[104] **Open standards** are perceived as a vehicle of innovation and recommended by the EU, however there is no initiative to oversee that they are really developed and promoted.

The **open science policy** of the EU has been a pioneering R&D policy. However, several interviewees think that it has not provided a proper **balance** between openness and **protection of intellectual property rights** (IPRs), does not have clear guidance about **responsibilities and quality** assurance and does not support the development of adequate **business models for commercialisation**. Striking the right balance between IP and open science policies is seen as essential to ensure that R&D&I partners can benefit from and cooperate on scientific work.[105]

[102] Traficom press release of 27.11.2019: https://www.kyberturvallisuuskeskus.fi/en/news/finland-becomes-first-european-country-certify-safe-smart-devices-new-cybersecurity-label; the certification label website can be found here: https://tietoturvamerkki.fi/.

[103] EMA, Fast-track procedures for treatments and vaccines for COVID-19, 2020; European Commission, Coronavirus and the EU Vaccines Strategy, Q&A of 24.09.2020.

[104] Plenary session at the EU Industry Days, Lesson learnt from COVID crisis? Resilience through increasing Europe's strategic capacity, 24 February 2020.

[105] EARTO, Towards a Balanced Approach Between IPRs and Open Science Policy, EARTO Paper of 31.07.2020; The Lisbon Council, ESADE and CWTS, Study on Open Science: Monitoring Trends and Drivers, Open Science Monitor, 2019, pp. 30-33.

4.1.3. Successful policies

Technological sovereignty and R&D&I are currently **high on the political agenda**, which has resulted in the adoption of several unprecedented policies that will support the development of KETs. In particular, this concerns policy options that support their commercialisation and early adoption of innovation. For example, **higher technology readiness levels (TRLs) and commercialisation** of a variety of digital technologies (AI, cybersecurity and connectivity) are targeted by the digital Europe programme. Deployment of a range of KETs that enable green and digital economy will be promoted through the European Green Deal and Recovery and Resilience Facility,[106] as well as the national recovery plans, which seem to prioritise research, innovation and education.[107] These funding instruments **follow in the steps of Horizon 2020**, which many interviewees considered a successful programme. The new instruments consider higher TRLs, scale up and use of public funding to unlock private investment.

Box 4.3: SMEs participation in EU-level funding

According to the Horizon 2020 Dashboard, **Horizon 2020** increased SMEs participation in comparison to FP7 very fast and achieved its target of 20 % SME participation in its funding calls. SMEs received €10.4 billion or 17 % of the available public funding. The **European Innovation Council** (EIC), which will be fully implemented under Horizon Europe, has a budget of over €10 billion to support emerging and breakthrough innovations by SMEs and start-ups. The main SME support instrument – **EIC accelerator** – provided its first equity investments worth €178 million to 42 SMEs (January 2021). Finally, the Commission decided to exempt SME Seal of Excellence projects under Horizon Europe from the obligation to notify State aid.

The overhaul of the old procurement rules and the adoption of the **2014 Procurement Directive** is considered a successful policy move. The new directive created a common framework for innovation procurement and introduced a procedure called innovation partnership. It has the potential to overcome the complexities and uncertainties surrounding pre-commercial and commercial procurement in the R&D&I context.[108] However, as noted in Section 6.3.1, the implementation and application of this directive at national and sub-national level is not consistent, preventing the achievement of the intended innovation procurement across Europe.

Considering the role of public funding in promoting innovation, several interviewees argued that some recent **exemptions from State aid rules** are going to help KETs development and deployment. In particular, the State aid exemption for important projects of common European interest (IPCEI)[109] and the two projects on European Battery Innovation and on microelectronics[110]

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[106] For instance, the Member States are encouraged to enhance their research and other efforts in ICT (5G connectivity, cybersecurity), AI, microelectronics, semi-conductors and to strengthen key value chains and access to critical raw materials. See European Commission, Guidelines to Member States Recovery and Resilience Plans – Part 1, 2021.

[106] Andhov M, Innovation Partnership in the New Public Procurement Regime – A Shift of Focus from Procedural to Contractual Issues

[107] Based on reviewing the published national recovery and resilience plans of France, Germany, Italy and Spain.

[108] Andhov M, Innovation Partnership in the New Public Procurement Regime – A Shift of Focus from Procedural to Contractual Issues?, 24 Public Procurement Law Review, Issue 2, pp. 18-31, 2015.

[109] Communication from the Commission — Criteria for the analysis of compatibility with the internal market of State aid to promote the execution of important projects of common European interest, OJ C 188 of 20.6.2014.

[110] See European Commission, State aid: Commission approves €3.2 billion public support by seven Member States for a pan-European research and innovation project in all segments of the battery value chain, Press release of 09.12.2019; European Commission, State aid: Commission approves plan by France, Germany, Italy and the UK to give €1.75 billion public support to joint research and innovation project in microelectronics, Press release of 18.12.2018 and European Commission, State aid: Commission approves €2.9 billion public support by twelve Member States for a second pan-European research and innovation project along the entire battery value chain, Press release of 26.01.2021.

that were approved under it, as well as the SME Seal of Excellence projects under Horizon Europe,[111] are seen as good examples of how EU State aid law can support KETs. A similar exemption may be granted to a new IPCEI on clean hydrogen.[112] However, an assessment of EU State aid rules during Covid-19 highlighted the need to put more focus on strategic goals such as the green and digital transitions and the inclusion of SMEs.[113]

While there is certain criticism of the EU's standardisation policy (see 4.1.2), **open standards and the promotion of interoperability and common standards** are considered successful approaches. Interoperability and common standards help overcome the fragmentation of the single market and develop joint solutions. The development of open standards usually involves contributions from more stakeholders (compared to traditional standardisation processes), enhances the adoption of technology, and incentivises innovation.[114]

4.2. Gaps and challenges for EU policy-making

This section provides an overview of the main challenges for policy-making and implementation in the EU, identifies areas of insufficient coverage by policies, or gaps. Whereas the challenges listed in Section 2.2.1 focused on the EU's performance in terms of KETs, this section identifies those issues where EU-level policies underperform. As such, this section provides suggestions for further action at the EU level.

4.2.1. Challenges of policy-making and implementation

Policy and institutional inertia have been identified as challenges to policy-making for KETs. The procedures for making policies and laws are lengthy, unable to keep pace with technological developments and are often reactive. This may be because policy-making structures are geared towards more traditional policy areas and not technology. There may also be resistance to change due to socio-economic factors (e.g. perception that society is not ready for a certain development). Institutional and administrative inertia may also prevent timely implementation of policies.[115]

The effective and efficient implementation and application of policies and laws is complicated due to the **administrative burden**. Several interviewees think that there is still a lot of red tape in the EU, especially to access public funding. The different tiers of EU multilevel governance are difficult to comprehend, even for the authorities themselves, making the processes more obscure and less attractive.[116]

Some stakeholders observe that there is still (regulatory) **competition between Member States**. For example, in attracting start-ups, creating national champions, developing standards or

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[111] European Commission, Press release, State aid: Commission simplifies rules for aid combined with EU support and introduces new possibilities to implement aid measures supporting the twin transition and the recovery from coronavirus pandemic, 23 July 2021

[112] Simon F, Five countries object to EU's latest hydrogen 'manifesto', EURACTIV of 18.12.2020.

[113] Van Hove, J., Impact of state aid on competition and competitiveness during the COVID-19 pandemic: an early assessment, 2020.

[114] Open Standards, Open Source, and Open Innovation: Harnessing the Benefits of Openness. A Report by the Digital Connections Council of the Committee for Economic Development, 2006.

[115] Schneier B, We must bridge the gap between technology and policy-making. Our future depends on it, World Economic Forum, 2019; Fenwick MD, Kaal WA and Vermeulen EPM, Regulation Tomorrow: What Happens When Technology Is Faster than the Law? American University Business Law Review, Vol. 6, No. 3.

[116] On the lack of clarity and administrative burden associated with public investment via EU public funds see Chapter 5 in OECD, Strengthening Governance of EU Funds under Cohesion Policy: Administrative Capacity Building Roadmaps, 2020.

certificates.[117] This is counterproductive to the development of the EU's technological sovereignty and to finding common solutions. It is perceived that EU Member States cannot compete individually at a global level, and a coordinated EU approach is needed.

4.2.2. Gaps in EU policies

The EU's policies related to **commercialisation and uptake of R&D&I** contain specific gaps and are insufficiently addressing the challenge identified in Section 2.2.1, namely bringing KET research to the market. While the new financial instruments are likely to increase and unlock the funding necessary for these activities, **supporting structures and frameworks are lacking**. One example is that interviewees noted that researchers and start-ups **lack the skills and knowledge for turning their ideas into products and services and how to market these**. They have difficulty finding the first customer and developing the demand for their products. Researchers and start-ups do not have the concepts to valorise their R&D – nor do they get support on how to develop such concepts and respective business models. This **lack of entrepreneurial skills** has also been noted in past assessments.[118] At the same time, traditional lenders (banks) **lack understanding of KETs** and KETs companies, and apply unsuitable financing approaches to them, which slow down product launches and innovation.[119]

Many KETs depend on the availability of high quality, diverse data sources, which is a critical input and a type of 'raw materia' for them (see also Section 2.2). Several interviewees argued that **Europe is lagging in big data development and database creation.**[120] At the same time, European data are moved out of Europe. More incentives are necessary to keep European data in Europe and to create the necessary datasets based on European values. At the same time, some EU data protection rules may be hindering the creation of the datasets necessary to develop certain KETs, due to their restrictiveness and complexity.[121]

A few interviewees mentioned the problem of **science espionage** that has gone largely unnoticed by policy-makers – up until very recently.[122] There are no current studies to confirm how widespread the problem is in the EU. Yet, at least over the last decade, several incidents have found their way into the mainstream news.[123] Of specific interest are the subjects of quantum computing[124] and, especially during the Covid-19 pandemic, vaccine development.[125]

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117 Analysis of regulatory competition in company law can be found in Giudici P and Agstner P, Startups and Company Law: The Competitive Pressure of Delaware on Italy (and Europe?), European Corporate Governance Institute - Law Working Paper No. 471/2019.

118 European Commission, Commission Staff Working Document. Impact assessment – Proposal for a Regulation of the European Parliament and of The Council establishing Horizon Europe, SWD(2018) 307 final.

119 Di Pietro P, Access-to-finance conditions for KETs companies, Study for the European Commission, 2016.

120 For example, for life sciences, the report by the joint task force of the European Medicines Agency (EMA) and Heads of Medicines Agencies (HMA) acknowledges the limited expertise in big data and available data sources. HMA-EMA Joint Big Data Taskforce, Evolving Data-Driven Regulation, Phase-II report, 2019.

121 Gérot M and Maxwell W, Will the GDPR frustrate Europe's plans for AI? ITProPortal of 18 March 2020; Chivot E and Castro D, What the Evidence Shows About the Impact of the GDPR After One Year, Center for Data Innovation, 2019.

122 The EUObserver reported that in February 2020 the European Commission sent out a concept note to national authorities and universities alerting them to espionage and advising them to establish counter-intelligence measures. Rettman A, Universities in EU on alert to China spy threat, EUObserver of 23.04.2020.

123 For example, confidential reports of the Belgian authorities on the problem date back to 2010. Rettman A, China suspected of bio-espionage in 'heart of EU'. EUObserver of 06.05.2020; Ekblom J, Chinese academic suspected of espionage banned from Belgium, Reuters of 30.10.2019.

124 O'Neill P, How suspicions of spying threaten cross-border science, MIT Technology Review of 02.12.2019.

125 Barnes J and Venutolo-Mantovani M, Race for Coronavirus Vaccine Pits Spy Against Spy, The New York Times of 05.09.2020; Sabbagh D and Roth A, Russian state-sponsored hackers target COVID-19 vaccine researchers, The Guardian of 16.07.2020.

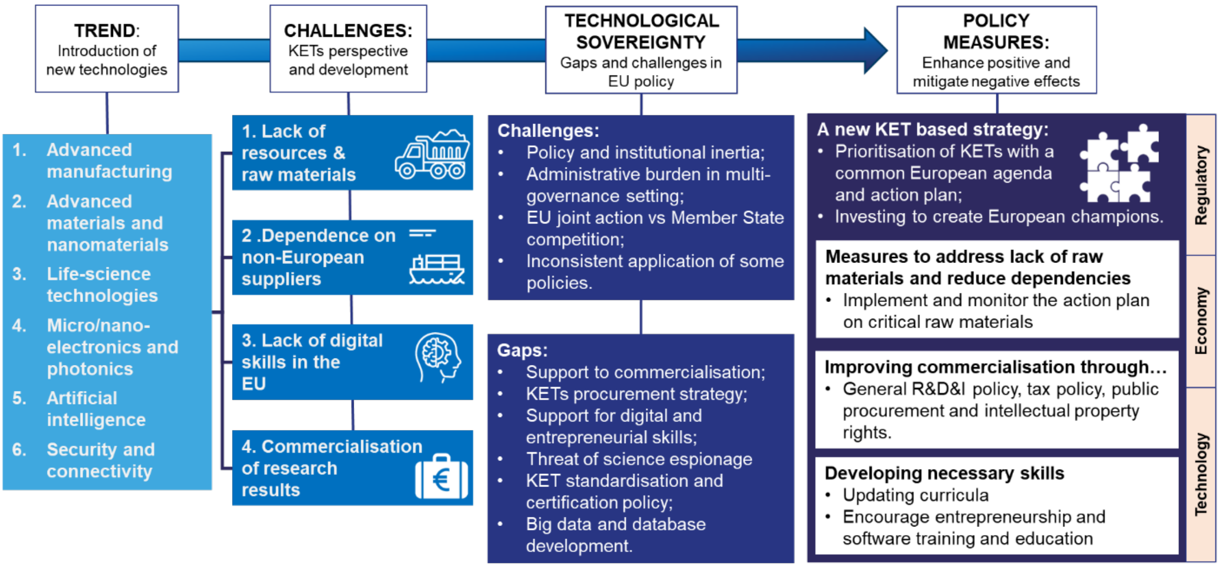
4.3. Policy options to enhance technological sovereignty

Policies need to be targeted in order to effectively address identified challenges and gaps. In Section 2.2 we identified four key challenges across the six KETs (access to resources, dependence on non-European suppliers, digital skills, and commercialisation). Moreover, in the preceding sections of this chapter, we outlined the shortcomings and gaps in existing policies resulting in a **regulatory fragmentation as a fifth challenge**. Based on this assessment, we developed a set of policy options. While not comprehensive, Figure 4.1 summarises these findings and provides an overview of our conceptual framework in developing policy options.

We have organised policy options into four packages. Three packages address the four key challenges across the KETs. They are, however, not KETs-specific, and will therefore contribute to improving the access to raw materials, reducing dependence on non-European suppliers, advancing skills and commercialisation overall. Therefore, in addition to challenge-based policy options, we propose a package of KETs-based options that would help to focus efforts on the key technologies. Most policy options are for EU policy-makers, but we also indicate those that could be taken at national level.

Moreover, these four packages **follow the definition of technological sovereignty and its three key elements**: **technology, economy, and regulation**. Specifically, the regulatory element comes into play in Section 4.3.1 focusing on a common European approach to deal with fragmentation. The economic element is addressed in Section 4.3.2, dealing with the two challenges of access to raw materials and the dependece on non-European suppliers. Finally, technology is addressed in Sections 4.3 .3 and 4.3.4, which focus on providing necessary skills as well as improving the uptake of research results. Of course, there is a certain overlap as, for example, skill policies and R&D uptake address economic aspects such as commercialisation.

Figure 4.1: Conceptual framework for developing policy options



Source: Authors' own work.

Beyond these four packages, two general policy options can be formulated based on discussions with stakeholders. First, a **more coordinated and inclusive approach is necessary for different policy areas and instruments**. For example, a continuous policy dialogue with Member States and stakeholders could be institutionalised in a forum. Such a forum would find synergies, but also provide room to discuss how current events shape strategic considerations, e.g. the role of KETs in national recovery plans.[126] Second, policy-making should be evidence-based: **indicators to measure regulatory impacts** (see Appendix 2, section 6.2.3 for our suggestions) **and monitoring and evaluation frameworks for all KETs** could be introduced and used to better respond to issues. These approaches are likely to help overcome the harmful competition between Member States (see section 4.2), while providing the basis for joint effort, providing a space for mutual learning and developing common ideas, exchanging best practices, and assist in overcoming administrative inertia.

4.3.1. KETs-based strategy for a common European agenda

As an overarching policy action that could strengthen European performance in KETs, the original **KETs strategy** of 2012 needs to be **updated and overhauled**.[127] This would increase awareness of the importance and the challenges of new technologies, reinforce Member States' joint commitments, and provide a stronger focus and support for national actions (e.g. national actions planned under the EU Recovery and Resilience Facility). The new KETs strategy should be nuanced: it could assign **different levels of priority to different KETs**, based on how the EU scores in global comparison and where the KET-specific weaknesses lie (see the analysis of the EU's global leadership in Section 3.2). The KETs strategy could then envisage more targeted actions for 'stronger' KETs and 'weaker' KETs.

The new KETs-based strategy could integrate R&D&I policy with elements of industrial policy and include a **common European agenda or action plan under EU leadership**. One of the objectives could be the nurturing of **European champions**, including by supporting cross-border cooperation and projects and granting **State aid or competition law exemptions** (e.g. by extending the use of IPCEI). Such coordination of resources would help in competing with large countries such as China or the USA. However, these efforts should lead to the creation and strengthening of value chains across Member States, and not national champions, by encouraging all Member States to participate and by monitoring whether funding is in line with the conditions set in State aid rules, as well as whether it also benefits SMEs.

[126] For example, the ambition of several Member States to use the Recovery and Resilience Facility to invest in and strengthen the European semiconductor value chain. See: European Commission, Joint declaration on processors and semiconductor technologies, 2020.

[127] European Commission, A European strategy for Key Enabling Technologies - A bridge to growth and jobs, COM(2012) 341 of 26.06.2012. There are several EU-level strategies that mention KETs and provide specific actions that would support KETs, like the New Industrial Strategy for Europe and An SME Strategy for a sustainable and digital Europe. These strategies can provide some building blocks and supporting structures for KETs strategy.

Box 4.4: Third-country example: Chinese KETs strategy

The **Made in China 2025 strategy** aims to advance China's leadership with the help of new technologies in key industry sectors: IT, high-end computing and robotics, renewable energy, aerospace, agriculture, high-tech maritime, new materials, railway, biopharma and medical devices. The toolbox of policy instruments deployed is impressive. *Tax preferences* will incentivise foreign firms to shift production and R&D to China. *Domestic standards, IP and competition policies* encourage the know-how transfer to Chinese firms and the use of Chinese components' suppliers. Huge *government subsidies* (US$426 billion) support domestic R&D and overseas acquisitions. *Company establishment and investment rules* drive foreign companies to create joint ventures with Chinese firms. *Licensing rules* are used to grant access to technology at a discount or technology transfer. China promotes *foreign exchange for R&D*: leading universities create Chinese campuses, and Chinese technology firms have R&D facilities abroad. China encourages *return of its educated expatriates and hiring of foreign talent*. See Appendix 6.3 for more details on Chinese KETs-related policies.

The KET strategy should strongly promote **bottom-up processes**. On the one hand, diversity and **smart regional specialisation** are important drivers of innovation.[128] On the other hand, **SMEs and start-ups** should be at the centre of the strategy as engines of innovation. Several interviewees commented that **SMEs and start-ups** still experience difficulty in applying and securing public funding and argued that **rules and procedures need to be simplified** for such companies to participate in publicly-funded R&D&I activities.

Likewise, interviewees also noted the difficulties companies face in **finding private funding** in the EU, not specifically for start-up funding, but during later funding rounds to grow out of the start-up phase. Besides an actual lack of available financing, the issue is mainly that smaller companies seem to lack the resources to search and apply for funding. Making information accessible through the access to finance portal, InvestEU and similar is crucial.[129] In addition, the combination of financing instruments and advisory services as provided by the European Investment Advisory Hub is crucial for smaller companies, especially in high-tech sectors that might struggle to access financing from a risk-averse traditional banking sector.[130] Many of these actions are new and should be monitored in their effectiveness and efficiency; additional actions could focus on strengthening intermediary organisations such as cluster organisations, which could provide more direct support to their members.

While there is a lot of public funding available via newly adopted, improved financial instruments (Horizon Europe, digital Europe programme), these could be adjusted to **specifically target the development and deployment of KETs**. Funds could be earmarked for KET investments. There could be a requirement or recommendation for a certain percent of public R&D funding to go to KETs.

128 OECD, Innovation-driven Growth in Regions: The Role of Smart Specialisation, 2013; European Commission, The role of Universities and Research Organisations as drivers for Smart Specialisation at regional level, 2014.

129 The Access to finance portal helps companies to apply for loans and venture capital supported by the European Union in their country, while the new InvestEU Portal connects investors and project promoters on a single EU-wide platform providing a database of investment opportunities. Other initiatives such as Startup Europe and the Innovation Radar show that there is already a wealth but also a complexity of supporting measures.

130 The Investment Advisory Hub set up by the EIB Group and the European Commission provides a single entry point for advisory services and technical assistance for investment projects in the EU.

Box 4.5: ATI Observatory

The **ATI Observatory** merges the previous KETs Observatory and the Digital Transformation Monitor. It monitors indicators across 8 dimensions related to creation and use of 16 advanced technologies: AI, AMT, advanced materials, augmented and virtual reality, big data, blockchain, cloud computing, connectivity, industrial biotechnology, IoT, micro- and nanoelectronics, mobility, nanotechnology, photonics, robotics and security. Monitoring could be complemented with the policy and regulatory indicators suggested in Appendix 2, section 6.2.3. The ATI dashboard could then provide a complete picture on KETs.

The new KET strategy needs to include a set of **indicators to measure the impact of policies and regulations** – and thus the progress of the common European KET agenda. For this, building on the ATI Observatory, a greater focus on policy and regulation could be established, with the mandate to monitor the indicators for all KETs and regularly report on the developments. This KET observatory could also serve as a centre of expertise, accumulating knowledge, collecting best practices and sharing information on what works and why.

A successful KET strategy needs to be regularly updated through a **continuous policy dialogue**. This also includes looking at what third countries are doing (see Appendix 6.3), not only to learn, but also to spot unfair practices. The issue of **science espionage needs to be further investigated** and recent defensive policy measures, such as the EU's foreign investment screening instrument and the modernised EU export controls mechanism[131] need to be reviewed in their effectiveness to ensure sensitive and emerging technologies are brought to market in the EU (see Box 4.6 for similar US policies).

Box 4.6: Export control and investment screening in the USA

On **science espionage**, the USA launched an awareness campaign on economic espionage in 2015, which provided case examples, explained how spies get access and what companies can do to prevent it. However, increased scrutiny of Chinese researchers in the USA and of collaborations with Chinese universities has led to concerns over unfair persecution hurting scientific collaboration. On **export control** and **FDI screening rules**, the USA protects its technological sovereignty by restricting transfer of *critical technologies*. The relevant legislations – the **Export Control Reform** Act (ECRA) and the **Foreign Investment Risk Review Modernization Act** (FIRRMA) – were updated in 2018. Critical technologies are included in the ECRA are among others, biotechnology, AI, microprocessors, data analytics, quantum information and sensing, additive manufacturing, robotics, brain-computer interfaces, hypersonic weapons, and advanced materials. The ECRA *restricts licensing of critical technologies* and allows the executive branch *to limit or ban exports at discretion if they provide military or intelligence advantage*. The FIRRMA allows the *review of* certain *FDI*, including *non-controlling investments in US companies active in critical technologies or sensitive sectors*, to determine *their impact on national security*. See Appendix 3, section 6.3.1 for more details on relevant US policies.

4.3.2. Addressing the lack of raw materials and data to reduce dependencies

The lack of resources and raw materials necessary for technological progress and the heavy dependence on non-European companies in the supply and value chain have been identified as two major challenges across all six KETs. This problem is not new: the EU is aware of it and has attempted

131 European Commission, Press release, Commission welcomes agreement on the modernisation of EU export controls, 9 November 2020; and European Commission, Press release, EU foreign investment screening mechanism becomes fully operational, 9 October 2020.

to deal with the problem since at least the 1970s.[132] In 2008, the European Commission suggested a more structured approach to the problem by adopting the Raw Materials Initiative.[133] This initiative was overhauled in September 2020 with the action plan on critical raw materials (see Box 4.8), which recently cumulated in the European Raw Materials Alliance.

Considering that a package of new measures has only recently been adopted, the Member States and the European Commission **could implement the action plan in its entirety effectively and without delay**. The EU could **monitor the implementation of the action plan** (e.g. jointly by the European Commission and European Parliament) and its efficiency and adjust the action points, if necessary.

Box 4.7: EU action plan on critical raw materials

The EU has identified **30 raw materials as critical**, based on their application in key sectors (e.g. aerospace) and future technologies, high supply risk due to import dependence, high concentration of supply in particular countries and lack of viable substitutes. The list of critical raw materials includes lithium, bauxite, light and heavy rare earth elements, titanium, and strontium, and can be revised.

The action plan sets **four main objectives** to ensure secure and sustainable supply of critical raw materials for the EU: 1) developing more resilient value chains for EU industrial ecosystems, 2) reducing dependency on primary critical materials through circular use of resources, sustainable products and innovation, 3) strengthening domestic sourcing of raw materials, and 4) diversifying the sourcing from third countries.

Ten action points with a specific timeline (until 2025) are proposed. An industry-driven European Raw Materials Alliance will be set up to focus first on resilience in rare earth and magnet value chains. The EU will develop sustainable financing criteria for extractive, exploitation and processing mining activities. R&D&I activities will be launched to develop and improve waste processing and substitution of critical materials, including through Horizon Europe. Secondary supply of critical raw materials will be investigated, through mapping the EU stocks and waste and identifying viable recovery projects. The resource exploration will be supported by remote sensing and earth observation programmes. Also, mining and processing projects will be identified, and their investment needs to be studied and matched to funding opportunities. This will be accompanied by developing skills and expertise in sustainable mining, extraction and processing. Responsible mining for critical raw materials will be promoted in the EU and internationally. To secure diversified supply, strategic international partnerships will be developed, accompanied by suitable funding.

As explained earlier, data can be considered a 'raw material' or input for many KETs. Open data policies are extremely advantageous for industry, giving access to enormous amounts of public sector data. **Open data should become standard at all levels of government**, and similar approaches encouraged across the private sector, where feasible.[134] To ensure the availability of data for the development of new technologies (e.g. IoT, AI), **data regulations** could be assessed and potentially revised, in particular making them **simpler to comply with** for SMEs and start-ups. The

[132] In 1970s, the European Commission set up an expert body called Raw Materials Supply Group comprising industry, environmental NGOs, trade unions, Member States, and candidate countries. The group meets regularly and provides advice on policy matters. The group creates working groups based on individual raw materials or problematic issues – depending on the need.

[133] European Commission. The raw materials initiative — meeting our critical needs for growth and jobs in Europe. COM(2008) 699 of 04.11.2008.

[134] Feasible refers to it being reasonable in an economic sense and being legally allowed. In fact, even personal data can be open data if all consent requirements are complied with or where the data is completely anonymised.

EU has recently proposed a new regulation to further promote the sharing of the valuable data resource (see Box 4.7). We recommend its swift adoption and effective implementation.

Box 4.8: Enhancing the use of European data for Europe

In November 2020, the European Commission proposed a new regulation – the **data governance act** – to facilitate data sharing across the EU and between different sectors of the economy. It provides a basis for a *European model of data governance*, based on the EU rules for data protection, consumer protection and competition law. The approach to data governance aims to *increase trust* between all stakeholders. The proposed regulation suggests *neutrality and transparency obligations for data intermediaries* – companies organising data sharing or pooling. The *reuse of publicly held data that is protected by IPRs or confidentiality* is facilitated. A concept of *data altruism* is suggested, meaning that companies and individuals can voluntarily make their data available for the common good (like scientific research).

4.3.3. Developing necessary skills

Skills were another main challenge across all KETs. Education and training policies can be adjusted to focus more on KET-related issues. The **EU level programmes** should continue to promote academic exchange and collaboration with third countries, but **special initiatives** could target **countries and institutions that lead in specific KETs** (see Section 6.2.2 for leading countries in university rankings). At the national level, education and training relevant to different KETs could be prioritised through **updating curricula**, making the subjects more applied and attractive for students.

The **EU could support national efforts** by studying and sharing best practices and bringing industry into the discussion on skills needs with educational institutions. A good example that could be replicated for all KETs is the ongoing study for DG GROW that produced curriculum guidelines for advanced manufacturing technologies.[135] In addition, DG EMPL's Blueprint for sectoral cooperation on skills could also provide fora to discuss the inclusion of KET-relevant skills (e.g. see the recently started European Software Skills Alliance),[136] while the Erasmus+ programme could be used to encourage work placements in KET-related sectors.[137] Similarly, with the STEM Alliance, a platform already exists for exchange between industries and Ministries of Education. Finally, one can also look at third country examples to learn how digital and KET-related skills can be integrated in curricula (see Box 4.9 on Korea's National Programme of Excellence in Software).

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135 PWC, Curriculum guidelines for Key Enabling Technologies (KETs) and Advanced Manufacturing Technologies (AMT). Study for EASME and DG GROW, 2019.

136 European Commission, Six new transnational cooperation projects to develop sectoral skills selected for Erasmus+ funding, 4 September 2020.

137 Erasmus+ already provides training opportunities for staff in higher education, vocational education and training, school education, and adult education. Specific training programmes could target digital or STEM skills and facilitate exchanges between companies and educational institutions in KET- relevant sectors.

Box 4.9: Third-country example: South Korean software education initiative

In 2015, the Republic of Korea launched a National Programme of Excellence in Software aiming at nurturing talent and strengthening capacities of students, businesses and the society as a while for the 4th Industrial Revolution. This programme specifically targets the development of skills for creating and using such technologies as AI, robotics, IoT, AMT and quantum computing. The curricula were revised to include mandatory coding courses in all middle and elementary schools, starting in 2018 and 2019 respectively, as well as in high schools. Before that, teachers had to be trained – both universities and the private sector stepped in to offer relevant courses, often for free. The number of software-centred universities – where all students have mandatory software education and coding training – is being increased to twenty. Universities are also offering 'software convergence majors' where other disciplines are combined with software education. Community software education courses are offered in cooperation with municipalities and by companies. The software education typically includes six main topics: Big Data, Healthcare IT, Management IT, Design, Simulation, and FinTech. See Appendix 3, section 6.3.1 for more details on the relevant Korean policies.

Entrepreneurship training for researchers, start-ups and SMEs could also be paid more attention. For researchers, such training could be part of their university curriculum, while SMEs and start-ups could be offered this via innovation hubs and incubators, or through cluster organisations. National level action could be supported by the EU identifying and sharing best practices. All these actions could be implemented through existing support infrastructures, such as the DIHs and the EU Smart Specialisation Platform's Technical Assistance Facility, which already supports businesses in improving their business plans and investment readiness. Finally, to foster an organisational culture that is R&D&I friendly and to encourage adoption of new technologies, the **development and maintenance of horizontal skills** (like digital skills) should be life-long, both for the work force and for general population.[138]

4.3.4. Improving commercialisation of R&D&I

The fourth identified main challenge for KET development, and in particular deployment, is commercialisation. The entrepreneurship training mentioned above already tackles this issue. Below, we introduce a few more options in the areas of R&D&I, public procurement, taxes, and IPR policies.

General R&D&I policy

Europe needs a **change of mindset** – both in the public and private sector, including financial institutions – to promote a **research and innovation culture** and to fight risk aversion. This could be achieved by communication campaigns at the EU and national level to raise awareness of the meaning and importance of R&D&I. Innovation happens everywhere, so innovation thinking should be an integral part of the business model, organisational culture and processes. National administration and company staff need to be alerted or trained to recognise the (potential of) innovation. The EU could create structures, frameworks and tools to develop and support this innovation spirit – and/or encourage Member States to do so.

[138] The OECD refers to the 'foundational skills' that are necessary in the economy and society in the face of the megatrends of globalisation, technological and demographic changes. Chapter 3 of OECD, OECD Skills Strategy 2019: Skills to Shape a Better Future, 2019.

Box 4.10: Third-country example: Regulatory sandboxes in the Republic of Korea

A highly regulated business environment has been seen as a major hurdle by Korean business organisations for innovation. In 2019, Korea therefore introduced a **new system of regulatory sandboxes** that provide companies more flexibility in testing and deploying innovative solutions. A public-private sandbox support centre, led by the Korean Chamber of Commerce has been established to review and approve applications for regulatory exemption periods. For example, this has led to wireless-charged electric buses and autonomous delivery robots to be allowed and tested on Korean roads. See Appendix 6.3 for more details on the relevant Korean policies.

For instance, **incentives for companies and the public sector to adopt and use new technologies** could be introduced to facilitate R&D commercialisation. These could be monetary incentives (e.g. tax credits or premiums, like for buying electric cars, or linked to direct funding through pilot projects), or training and education. **Innovation hubs** are a successful support structure for several digital technologies (DIHs).[139] Their model could be replicated **for all KETs**, and companies could be incentivised to partner with research and technology organisations (RTOs).[140] Specific requirements for RTOs to **involve SMEs and start-ups** or other incentives could increase the participation of small companies **in R&D&I activities**, both nationally and at the EU level. Collaboration with universities may also be beneficial for companies; RTOs tend to be closer to business needs, while university research tends to be more fundamental in nature.[141] Finally, regulation needs to be changed to encourage and allow **easier testing, piloting and early commercialisation**. This could include exemptions from State aid rules to enable funding of higher TRLs, fast-track market admission, as for Covid-19 vaccines, promoting regulatory sandboxes, or flexibility for national (regional or local) rules for testing, as in the case of automated driving.[142]

Public procurement

Innovation procurement would help establish an innovation-friendly culture in the public and private sector and would benefit new technologies in general, not only KETs. To strengthen innovation procurement by public sector, the EU could promote and support the **consistent and effective implementation and application of the 2014 Public Procurement Directive and the 2018 Guidance on Innovation Procurement.**[143] This is a joint effort by the EU and at national level. The EU could study the transposition of the directive and the practice of innovation procurement across the EU, identify problems, and then share best practices and provide further guidance and training for procurers. Emphasis could be placed on public procurement that may involve KETs and their applications (e.g. highlighting the role of cybersecurity or artificial intelligence in certain contexts, requirements to use open standards, open data or share data).

Member States could develop **national R&D&I procurement strategies** or guidance for domestic companies, based on 2018 EU-level guidance. Such measures could help change the mindset around R&D&I funding, both by public and private investors, which should not be considered as spending, but as a core part of investment.

[139] European Regional Development Fund (ERFD) and other organisations cite DIHs as best practice.

[140] For example, the Basque Industry 4.0 programme provides subsidies for R&D projects that involve technology transfer from technology providers to industrial companies. For more information see: https://basqueindustry.spri.eus/en/subsidies-4-0/.

[141] JRC. Research and Technology Organisations and Smart Specialisation, S3 Policy Brief Series, 15/2015.

[142] Some countries could permit testing of fully self-driving cars on public roads under restrictive conditions. See the example of the Dutch solution on the official website of the Dutch Road Authority (RDW).

[143] European Commission. Guidance on Innovation Procurement. Commission notice C(2018) 3051 of 15.05.2018.

Box 4.11: Third-country example: R&D&I tax incentives in Japan

In 2020, Japan updated its **open innovation tax incentive** promoting the investment of internal reserves of companies into venture companies. The investing company can *deduct 25 % of the venture investment from its taxable income*, with investment needing to be at least JP¥100 million (€786 900) in a Japanese company or JP¥500 million (€3 934 500) in a foreign company. Tax incentives need to be approved by the Ministry of Economy, Trade and Industry. Japan also introduced **tax incentives for 5G technology**. For qualifying investments, a Japanese company can receive either a *15 % tax credit or 30 % bonus depreciation*. Network operators and companies preparing 5G networks for smart factories and smart agriculture using AI in rural areas will be able to benefit from the incentive. Both incentives are available for qualifying investments made between 1 April 2020 and 31 March 2022. See Appendix 6.3 for more details on the relevant Japanese policies.

Tax policy

Greater tax harmonisation would establish a better balance between Member States and provide an incentive for cross-border investments. Currently, differences between tax (and other) regulations make it difficult for companies (especially smaller ones) to operate across EU borders. Furthermore, tax incentives could be used to **nudge large European companies to purchase European start-ups** and prevent them from being bought up by foreign companies. There are already various initiatives in place at the EU and national levels (e.g. innovation hubs, awards), which support and increase the visibility of start-ups, however harmonising taxes and State-aid compliant tax incentives could further support the growth of companies and commercialisation of R&D&I. Since taxation is a national competence, the EU could study European and third country examples (see Box 4.11) and recommend when tax policy could be used to promote such activities, as well as to point out harmful tax policies (including intra-EU tax competition).

Intellectual property rights

Commercialisation of R&D&I can be significantly improved if **IPR ownership** on products developed **in the context of public procurement remained with the companies**.[144] Because in the EU only some Member States (e.g. Germany) have adopted this approach, the EU could step in to promote and mainstream this practice. Considering that such a recommendation was already made in the 2018 Guidance on Innovation Procurement, either training and exchange of best practices can be envisaged or, as a stronger signal, an amendment to the 2014 Public Procurement Directive. This general rule could include exceptions for overriding reasons of public order and security.

On the other hand, a few interviewees suggested that the whole IPR system needs to be reconsidered because technologies develop fast and the current rules are holding them back.[145] The long duration of IPR protection (e.g. 70 years after the author's death for copyright) leads to large volumes of data being underexploited or forgotten. Data-driven R&D&I may be restricted by IPR protection of databases that relate to search, processing, analysis, storage and creation of data. This is an issue across all KETs, but specifically for those that are driven by data (e.g. AI), or that do not require large-scale investments and can be developed relatively fast, such as software. There are indications that **open source** is the future,[146] hence the EU could continue promoting this approach

[144] For evidence see European Commission, Economic benefits of leaving IPR ownership in public procurements with companies. Not dated.

[145] Crouzier T, Barbarossa E, Grande S and Triaille JP, IPR, Technology Transfer & Open Science, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-71790-1, doi:10.2760/789864, pp. 9-11.

[146] Anadiotis G, 2021 technology trend review, part one: Blockchain, cloud, open source, ZDNet of 11.01.2021.

where possible (e.g. in public procurement and PPPs) and build on the 2020-2023 open source software strategy.

4.4. Summary of policy options

In the previous section, we proposed various policy options to address current challenges and opportunities and to strengthen Europe's technological sovereignty in six KETs. These options vary widely in their ambition, the involvement of actors, and their linkage with existing policies. We summarise them below, together with providing an evaluation of their feasibility and an indication of the actors to be involved.

Regulatory fragmentation

As an overarching policy measure, we proposed a new **EU strategy for KETs**, building on an **institutionalised policy dialogue** between Member States, EU institutions and stakeholders (e.g. past members of the High-Level Expert Group on KETs). It addresses the regulatory element of the definition of technological sovereignty. The strategy could aim for a **coordinated approach, uniting EU and Member States' strategies behind the common goal of technological sovereignty in KETs**. This links closely to existing policies creating a European research area as well as the single market. Such a dialogue and the ensuing strategy could lead to increased awareness and reinforced commitments. It could include regions and SMEs in the implementation and build on their strengths. Monitoring of not only market and technology aspects of KETs, but also regulatory aspects could be ensured, to check implementation, identify and share best practices, and address the risks of new technologies. The institutionalised dialogue could be a continuous discussion on how technological and global developments affect Europe's technological sovereignty. Table 4.1 provides an overview of the specific suggested policy options.

Table 4.1: Policy options for a KETs-based strategy

Policy options	Actor and enablers	Feasibility
1. A common European agenda updating the strategy for KETs culminating in an action plan under the EU's leadership.	European Commission with Member States, and relevant industry stakeholders	This action could build on the previous KET strategy and start as a discussion forum generating commitments and slowly building an action plan.
2. Support development of European champions by supporting cross-border cooperation through State aid and competition law exemptions.	European Commission with Member States	Existing tools such as IPCEI facilitate this action, other similar tools could be developed. Market power, competition issues, and different Member States' needs should be considered closely.
3. Promote bottom-up processes for smart regional specialisation and monitor as well as facilitate the inclusion of SMEs in the strategy through one-stop shops and intermediary organisations.	European Commission with representatives of regions and SMEs	Existing platforms such as the Smart Specialisation Platform and the European Cluster Collaboration Platform could be used to involve regions and SMEs in developing the joint strategy and monitor their inclusion.
4. Target development of KETs through earmarking funds for KET investments.	European Commission with Member States	Could be implemented under newly adopted, improved financial instruments, such as Horizon Europe.
5. Strengthen KETs observatory focus on measuring the impact of policies and regulations and sharing best practices for forward-thinking policy-making, and monitoring the follow-up on KET strategy.	European Commission with AIT observatory and KET specific observatories	The existing observatory could be easily expanded to cover policy indicators. It would be difficult to come up with measurable indicators.
6. A continuous policy dialogue to update KET strategy and investigate new areas based on new findings.	European Commission with Member States, relevant industry and academic stakeholders	Setting up a forum that includes EU and Member State representatives could be relatively easy. However, ensuring follow-up actions and that commitments are made is more difficult.
7. Investigate the economic impact of science espionage at European level through a study.	European Commission, research and industry stakeholders.	Science espionage is a topic that has recently gained more attention and could be investigated further.

Such a strategy would itself consist of a multitude of actions, some of which we have proposed for various areas relevant to the development and deployment of KETs in Europe. These actions aim to address economic and technology elements of technological sovereignty. Specifically, we have **grouped additional policy options around the four identified challenges**. Table 4.2 presents these specific policy options, which aim to improve access to raw materials, reduce dependencies, improve relevant skills, and facilitate commercialisation of innovation in the EU.

Table 4.2: Policy options addressing the four identified challenges

Policy options	Actors and enablers	Feasibility
Dual challenge of access to critical raw materials (incl. data) and dependence on non-European companies		
8. Follow-up on implementation of the action plan on critical raw materials.	European Commission with Member States and industry	Feasible, as the action plan is established and with it the Raw Materials Alliance to follow up.
9. Monitor implementation of the action plan on critical raw materials.	European Commission and European Parliament	The EU could closely monitor follow-up on the action plan and adjust where necessary.
10. Promote open data policies across all levels of government (e.g. through the proposed data governance act) and encourage similar approaches for the private sector.	European Commission, European Parliament and Member States	Adoption, implementation and follow-up of the data governance act and further promotion of open data policies.
11. Assess data regulations and possibly revise them to make them simpler to comply with for SMEs and start-ups (e.g. through temporary exemptions).	European Commission with industry and academic stakeholders	Continuous evaluation is part of the EU policy cycle, for data regulation specifically, the impact on SMEs could be a focus.
Challenge of providing the relevant (digital) skills		
12. Target countries and institutions that lead in specific KETs for academic exchange and collaboration (e.g. through Erasmus+).	EU, research	Easy to implement, as it could be communicated through existing programmes.
13. Provide guidelines and best practices for including KET-relevant skills (digital, STEM) to update existing curricula.	European Commission with industry and academic stakeholders	Relatively easy, as it requires research into requirements and needs for new curricula as well as their promotion.
14. Encourage a stronger focus on entrepreneurship training for researchers, start-ups and SMEs.	Member States with European Commission and educational institutes	Partially depends on the actions at the national level, but could be promoted by the Commission through innovation hubs.
15. Encourage lifelong learning for horizontal skills such as digital ones.	Member States with European Commission and educational institutes	This largely depends on national (also regional and local) actions and implementation in educational facilities.
Challenge of commercialisation of R&D&I		
16. Promote a research and innovation culture to fight risk aversion.	European Commission and Parliament, Member States and business stakeholders	Long-term action that would require continued efforts to create a more entrepreneurial culture.
17. Incentivise companies and the public sector to adopt new technologies to facilitate commercialisation (e.g. tax credits, funding through pilot projects).	Member States with European Commission	Existing incentives could be reviewed by Member States. The Commission could share knowledge and best practices and ensure that there is no harmful regulatory competition between Member States.
18. Replicate the successful model of innovation hubs for all KETs and encourage involvement of SMEs.	European Commission with European digital innovation hubs (EDIHs)	With the EDIHs, a successful model already exists which could receive continued support to grow.
19. Facilitate testing and piloting of innovation through regulatory changes and/or regulatory flexibility.	Member States with European Commission and regional and local authorities	EU and national legislation could be reviewed to allow for regional/local regulatory experiments. Successful regional/local examples could be upscaled.

Policy options	Actors and enablers	Feasibility
20. Promote and support the consistent and effective implementation of innovation procurement across Member States.	European Commission with Member States and regional authorities	The Commission could study the difficulties faced by practitioners and adjust/specify guidance, share best practices, organise training.
21. Develop national R&D&I procurement strategies or guidance for procurement authorities.	Member States with regional authorities and relevant stakeholders	Member States could supplement the EU tools by addressing specific national needs.
22. Improve tax harmonisation across the EU to facilitate cross-border investments.	Member States with European Commission	Challenging, as tax systems vary widely across Member States. A long process that could be supported by guidance from the European Commission on best practices.
23. Consider the use of tax incentives to nudge large European companies to purchase European start-ups and increase the visibility of these start-ups at European level.	Member States with European Commission and business representatives	Similar to above, requires sharing best practices and learning from each other, but also careful consideration of unwanted intra-EU tax competition.
24. Update IPR ownership rules for products developed in the context of public procurement, so that ownership can remain with the developers for future business.	Member States with European Commission	Member States could take action to implement the existing guidelines at the national level. The Commission could support (exchange of best practices) or amend the directive.
25. Promote open-source approaches where possible (e.g. in public procurement and PPPs).	European Commission with Member States	Already being promoted through the open source software strategy, which could be followed up and further actions could be set-up easily.

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6. Appendix

6.1. Appendix 1 – Process and methodology of the study

6.1.1. Process

In this section, we present a **brief overview of the overall study methodology used**, which helps to clarify the process involved in drafting this report. The study process is built on 3 main tasks.

Task 1: KETs and their impacts

Task 1 focused on the **analysis of the six KETs** that are of paramount importance for Europe's technological sovereignty in the future. The results are reported in Chapter 2 with **easily accessible definition and perspective on KETs**, **their importance and potential for Europe, with respect to technological sovereignty, and social and economic impact**. A selection of case studies is also presented in order to illustrate the importance of specific technologies as part of the KETs and their impact. These are only illustrative examples as there is an infinite number of other relevant cases that are not included in the report. The chapter also summarizes **the main challenges of KETs and their impacts along the technological value chain.**

Task 2: KETs, technological sovereignty and leadership

Task 2 aims to provide an **assessment of Europe's performance with respect to technological sovereignty in the six KETs, particularly from the research and industrial perspective**. For this task, we first investigated the **concept of technological sovereignty** by providing a definition (reported in Chapter 1). We then proceed to the **identification, assessment and selection of indicators** reflecting technological sovereignty. Accordingly, in chapter 3, we provide an analysis of each identified indicator in order to assess **the position of Europe** compared to third countries, especially the USA and China.

Task 3: Policy Options

Task 3 was **focused on the development of policy options**, that are reported in Chapter 4. For this task, we first assessed a selection of existing policies contributing to technological sovereignty in order to **identify the gaps and challenges that prevent the effective development and implementation of policies in Europe** in relation to KETs. Then, **specific suggestions for policy options** are outlined to address the identified challenges and enhance the technological sovereignty of the EU, built on the assessment of existing policies and the conclusions of the preceding tasks.

6.1.1. Methodology

The overall study was built on the **data collected through desk research and inputs from interviews with experts.** Specifically, the approach used to identify sources of information is as follows:

- Ongoing political debates on technological sovereignty
- Relevant document on KETs and related areas
- Relevant policy and legislative document

We also conducted **24 interviews with experts** covering the 6 KETs from various types of organization as follows:

- 12 interviewees from the research community including national centres of research, research and technology organisations, academia

- 7 interviewees from industry associations
- 5 interviewees from policy organisations

These interviews helped to frame the KET challenges and their impact on technological sovereignty. They were also used to get an overview of the state of play in the EU in relation to the KETs, to support the definition of technological sovereignty, the selection of indicators, and to draft and assess the potential policy options.

In addition, at the halfway point of the project, we organised an **internal workshop among the core team members with the participation of the STOA administrator in charge**. The workshop served to reflect upon the initial findings and to discuss possible policy options to support Europe's technological sovereignty in KETs.

6.2. Appendix 2 – Methodology for the selection of indicators and related sources

6.2.1. Indicator selection

This is an explanation of the selection of indicators with regard to technological sovereignty. For each selected indicator, the following information is presented:

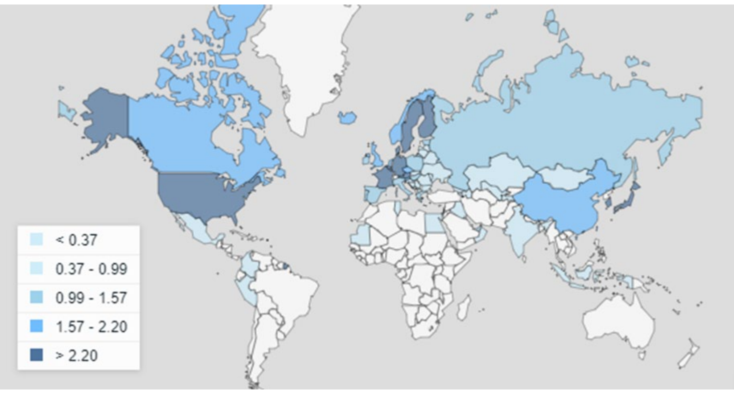
- The **relevance** of the indicator
- The **source** used
- The **limitations**
- The **type** (if KET-specific or global)
- The **assessment** method that will be used to compare the EU to the USA and China

Additional sources/analysis used to assess the EU position are also provided.

Domestic R&D intensity

- Relevance: Domestic R&D intensity (domestic R&D expenditures over GDP) shows the global effort of the country to invest in R&D. Source funds come from companies, government and private non-profit sectors. Several interviewees stated the importance of measuring R&D intensity as the basis for technology sovereignty, ideally per domain.
- Source: World Bank.
- Limitations: R&D funding is needed to support R&D but that does not drive business nor does it ensure economic growth with regard to technological sovereignty.
- Type: Global.
- Assessment method: qualitative, in terms of high, neutral or low according to EU position compared to third countries.

Figure 6.1: R&D Intensities in %, 2018



Source : https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=EU

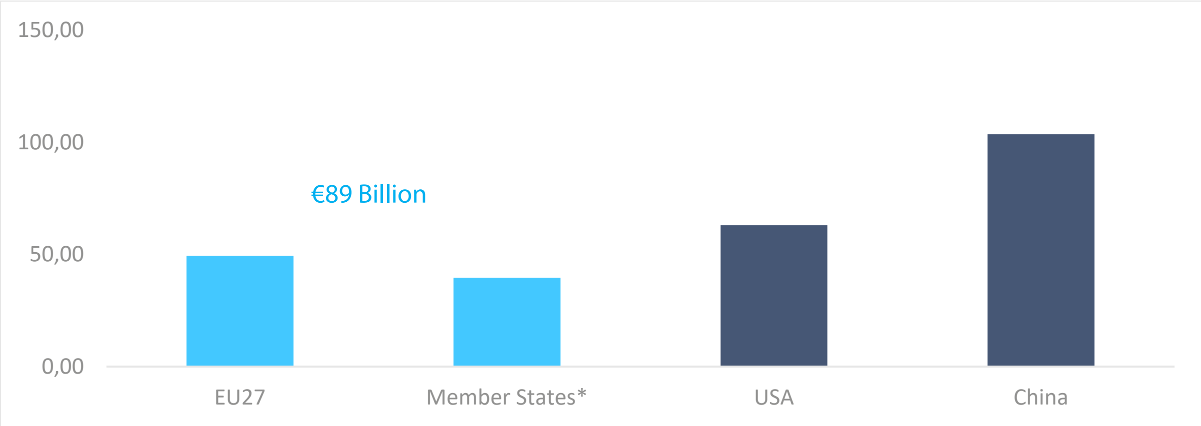
Public research programmes funding amount

- Relevance: dedicated budget from funding programmes is fundamental for research, development and innovation. Based on the benchmark of research programmes[147] targeting KETs, the capacity of countries to fund advanced technologies is measured. It also shows the political will to support specific KET with a dedicated budget.
- Source: Authors' own work, based on data extracted from the respective programmes.

[147] Produced by IDATE DigiWorld

- Limitations: R&D funding is needed to support R&D but that does not drive business nor does it ensure economic growth with regard to technological sovereignty. In addition, the benchmarking of public research programmes is not exhaustive, as it is based on public information, which is not detailed enough in terms of amount of funding and combines different time periods, making a rigorous comparison between countries/regions impossible.
- Type: Global (there is no systemic breakdown per KET for the programmes preventing an assessment per KET).
- Assessment method: qualitative, in terms of high, neutral or low according to EU position compared to third countries.

Figure 6.2: Amount for public funding programmes on all KETs at global level, € billion



Note: China €100 billion programme does not cover only the 6 KETs.

Source: Authors' own work, based on data extracted from the respective programmes.

Table 6.1: Benchmarking of public funding programmes related to the KETs

Name of the initiative/programme	Time period	Country/ Zone	KET keywords	Public funding amount (billion €)
Made in China 2025	2020–2025	CH	Advanced manufacturing, AI, Biotechnology, IoT, 5G and other non KET technologies	100
Next Generation Artificial Intelligence Development Plan	2018	CH	AI	1.9
Quantum Communications Initiative as part of the 13th Plan	2006-2020	CH	Quantum technology	1.7
Digital Strategy 2025	2016 – 2030	DE	Micro/nano-electronics	1
AI Made in Germany strategic plan	2018-2025	DE	AI, Biotech, 5G	3
Federal programme for Quantum Technologies	2021+	DE	Quantum technology	0.65

Name of the initiative/programme	Time period	Country/ Zone	KET keywords	Public funding amount (billion €)
Industrie 4.0 initiative	2011-2020	DE	Advanced Manufacturing	0.2
5G Initiative for Germany	2017 – 2025	DE	5G	0.08
National Research Strategy BioEconomy, Nationale Bioökonomiestrategie	2011 – 2030	DE	Biotechnology	1.95
From Material to Innovation, Action Plan Nanotechnology, 'DaNa – Data and Knowledge on Nanomaterials'	2013+	DE	Nanotechnology	0.6
'Mikroelektronik aus Deutschland – Innovationstreiber der Digitalisierung' & 'Forschungsfabrik Mikroelektronik Deutschland'	2012 - 2020	DE	Micro/nano-electronics	0.8
Photonik Forschung Deutschland - Licht mit Zukunft	2013 - 2020	DE	Photonics	0.1
Trustworthy Electronics programme	2021-2024	DE	Micro/nano-electronics	0.4
Spanish National Cybersecurity Institute (INCIBE)	2006 – 2020	ES	Cybersecurity	0.024
National ArtificialIntelligence Strategy (Estrategia Nacional de Inteligencia Artificial – ENIA)	2021-2023	ES	AI	0.6
Quantum Technology Flagship	2018 -2028	EU	Quantum technology	1
ENISA funding (Cybersecurity Act)	2019	EU	Cybersecurity	23
White paper on artificial intelligence	2020-2027	EU	AI	7
Europe's AI strategy	2018-2020	EU	AI	2.1
Europes' AI strategy	2018-2021	EU	AI	0.5

Name of the initiative/programme	Time period	Country/ Zone	KET keywords	Public funding amount (billion €)
Leadership in Enabling and Industrial Technologies (LEIT) ICT, DT, SU	2014-2020	EU	Micro- and nano-electronic technologies, Photonics, AI, Quantum Computing, Nanoelectronics, Cybersecurity, Electronic components, 5G	4.87
Leadership in Enabling and Industrial Technologies (LEIT) NMPB	2014-2020	EU	Nanotechnologies, Advanced Materials, Life science and Advanced Manufacturing	3.14
Digital Europe	2021-2027	EU	Quantum technology	2.2
Digital Europe	2021-2027	EU	AI	2.1
Digital Europe	2021-2027	EU	Cybersecurity	1.7
Digital Europe	2021-2027	EU	AI, Quantum technology, cybersecurity, Big Data	1.68
Artificial intelligence and Blockchain investment fund	2020	EU	AI, Blockchain	0.1
Stratégie nationale pour la cybersécurité	2019-2025	FR	Cybersecurity	1
Plan Intelligence artificielle	2018-2023	FR	AI	1.5
The National Plan for Quantum Technologies	2020-2025	FR	Quantum technology	1.8
Industrie du Future	2014-2020	FR	Advanced Manufacturing	10
Nano 2022	2019–2022	FR	Micro/nano-electronics	0.8
IPCEI on microelectronics	2018-2024	FR, DE, IT, UK	Electronic components and systems	1.75
Programma di supporto alle tecnologie emergenti 5G	2019-2025	IT	5G	0.075
The Italian Bioeconomy strategy	2020–2025	IT	Biotechnology	0.57
Piano nazionale Industria 4.0	2017-2020	IT	Advanced Manufacturing	13

Name of the initiative/programme	Time period	Country/ Zone	KET keywords	Public funding amount (billion €)
Society 5.0	2019–2034	JP	AI, robotics, cybersecurity and other digital technologies	31
AI for all people, industries, territories and government	2019–2025	JP	AI	2.5
R&D on Quantum Technologies	2019	JP	Quantum technology	0.227
The National Agenda on Quantum Technology	2020-2025	NL	Quantum technology	0.023
Basic and applied quantum research initiative	2019-2024	RU	Quantum technology	0.67
KISA project on Blockchain	2020	SK	Cybersecurity	0.0078
South Korea 2020 budget on technologies	2020	SK	Advanced Manufacturing	0.35
R&D on Quantum Technologies	2019-2024	SK	Quantum technology	0.034
The 'Manufacturing Industry Innovation 3.0.' programme	2014-2025	SK	Advanced materials, electronic components & systems, biotech, connected cars, AI	0.155
Fourth Science and Technology Basic Plan	2018-2022	SK	Advanced materials, electronic components & systems, biotech, connected cars, AI	7
National Cyber Security Strategy	2016–2021	UK	Cybersecurity	2.2
National Quantum Technologies Programme	2013-2019	UK	Quantum technology	1.1
AI in the UK: ready, willing and able?, AI Sector Deal	2018–2028	UK	AI	0.9
AI in the UK: ready, willing and able?	2018–2028	UK	AI	0.89
AI in the UK: ready, willing and able?, AI Sector Deal	2018–2028	UK	AI	2.5

Name of the initiative/programme	Time period	Country/ Zone	KET keywords	Public funding amount (billion €)
Bioeconomy strategy	2018–2030	UK	Biotechnology	1.2
Next Generation Mobile Technologies: A 5G Strategy for the UK	2016–2021	UK	5G	1.23
The Manufacturing Made Smarter Challenge	2019	UK	Advanced Manufacturing	0,03
DoD Microelectronics Innovation for National Security & Economic Competitiveness (MINSEC)	2019–2023	USA	Micro/nano-electronics	1.27
DARPA (military technologies projects)	1958–2020	USA	Cybersecurity	3.4
Cyber NYC (Cyber campus)	2017-2020	USA	Cybersecurity	0.1
Establishing a 5G Fund for Rural America	2020-2030	USA	5G	7.7
DHS's cybersecurity	2021	USA	Cybersecurity	0.95
The National Quantum Initiative Act	2019-2024	USA	Quantum technology	1
Trump administration AI Initiatives	2020+	USA	AI	3.6
Advanced Industries of the Future	2020–2022	USA	AI, Quantum technology	1.7
American Artificial Intelligence Initiative	2020	USA	AI	0.73
Manufacturing USA	2020+	USA	Advanced Manufacturing	0.1
National Institutes for Health (NIH)	2017-2020	USA	Biotechnology	23
National Cyber Strategy	2020-2021	USA	Cybersecurity	15.3

Name of the initiative/programme	Time period	Country/ Zone	KET keywords	Public funding amount (billion €)
National Nanotechnology Initiative	2018-2020	USA	Nanotechnology	4.14

Source: Authors' own work

R&D&I funding summary per KET

The table below presents **the EU position per KET as regards R&D&I funding**. It explains the source of funding for each KET, based on the inputs from the interviews and desk research for Europe and third countries' strategies on KET funding.

Table 6.2: Europe's position as regards research per KET

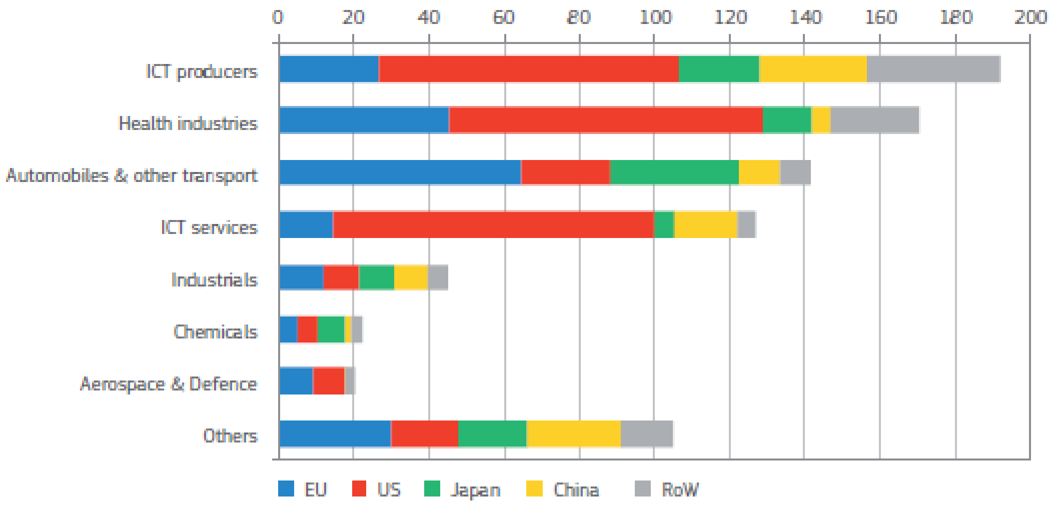
KETs	Europe position regarding R&D&I funding		Third countries strategies
Advanced manufacturing	High	Large and dedicated national funding initiatives driven by France and Italy	Large national programmes targeting several KETs in China, Japan and South Korea
Advanced materials and nanomaterials	Medium	Few dedicated public funding programmes notably for nanotechnologies in Germany	Strong support from the US government on nanotechnologies
Life sciences technologies	Low	Few national funding programmes for biotech notably in Germany	Very strong public and private investments from the USA
Micro/nano electronics and photonics	Medium	Strong support of public funding through various European and national programmes notably for quantum computing (France and Germany) Weak support for photonics	Strong involvement from the private sector in China and in the USA
Artificial intelligence	High	KET well-funded and supported through dedicated Europe and national programmes	Very strong support in the USA from both public and private technology companies in the USA
Security and connectivity technologies	Medium	Very strong support from Europe on cybersecurity with few national funding programmes notably in France Weak support for connectivity technologies	Strong investment from the US government in cybersecurity and connectivity (5G). Strong support from the Chinese government for connectivity (already started its national 6G research initiatives)

Source: Authors' own work

Business/private R&D expenditures

- Relevance: Effort from businesses in R&D is key to support public funding, especially to scale up.
- Source: The EU Industrial R&D Investment Scoreboard,[148] which provides an analysis of the R&D investments from the world's top 2500 companies in its 2019 publication.
- Limitations: R&D funding is needed to support R&D but that does not drive business nor does it ensure economic growth as regards technological sovereignty.
- Type: Global.
- Assessment method: qualitative, in terms of high, neutral or low according to EU position compared to third countries.

Figure 6.3: R&D Investment of the top 2500 companies for the EU, the USA and China in 2018 by main industries (billion EUR)



Source: 2019 EU Industrial R&D Investment Scoreboard European Commission, JRC/DG RTD

Number of STEM graduates

- Relevance: As STEM education refers to the teaching and learning of the science subjects, technology, engineering, and mathematics, it covers the subjects related to the 6 KETs. Also, STEM is important as the global economy and general well-being are based on them. This indicator needs to be monitored to assess whether the requiremenets for jobs of the future are being addressed. The number of PhD students would also be a good indicator in providing the number of students at the highest level of education, which is promising for the future.
- Source: World Economic Forum, 2017.
- Limitations: The number of STEM graduates is not sufficient to assess whether they will stay in the country as a future job holder.
- Type: Global.
- Assessment method: qualitative, in terms of high, neutral or low according to EU position compared to third countries.

[148] Jointly carried out by EC JRC and DG RTD.

Share in global patenting

- Relevance: Patents encourage the development and protection of innovations and new technologies in all fields, thus patents also reflect the capacity of inventors and businesses to innovate. The indicator of relative share in global patenting measures the share of patent applications for each country over all global applications in the respective advanced technology.
- Source: KET observatory/ATI project based on EPO (European Patent Office) database.
- Limitations: some innovations do not need to be patented and most patents do not get to the market. Also the EPO database is limited to patent applications filed in Europe.
- Type: KET specific.
- Assessment method: in terms of high, neutral or low according to EU position compared to third countries.

Share of international co-inventions

- Relevance: as collaboration increases scientific productivity, international co-inventions are a proxy for the quality of scientific research. The share of international co-inventions measures the percentage of patents shared based on the localisation of the inventors;
- Source: KET observatory/ATI project.
- Limitations: collaboration in patents is not enough to represent the benefits of international collaboration.
- Type: Global.
- Assessment method: in terms of high, neutral or low according to EU position compared to third countries.

Number of start-ups

- Relevance: This indicator evaluates the capacity to transfer the technology innovation to an entrepreneurship structure for KETs.
- Source: KET observatory/ATI project provides the number of Venture Capital (VC) backings for advanced technology start-ups - including KETs - established between 2010 and 2019.
- Limitations: By comparing absolute numbers of start-ups, it does not distinguish between a start-up with one single person and several persons.
- Type: KET specific.
- Assessment method: in terms of high, neutral or low according to EU position compared to third countries.

Industrial leaders ranking

- Relevance: The current industrial ecosystem landscape is very likely to influence future leadership in KET through the investment of industry and ability to transfer technology. Technological leadership in KET is essential for future industrial leadership, but also reciprocally. The EU-originated player position as part of the top 10 industrial leaders (by revenue) in the fields of industry related to KETs is considered for this indicator and provides a foretaste of its positioning as regards the global competitive system.
- Source: Authors' own work based on multiple sources.
- Limitations: The available rankings do not indicate how the leaders dominate the market and thus the relative dependence on them.
- Type: KET specific.
- Assessment method: according to the number of EU players appearing among the top 10 leaders: high if EU players are in the top 3, low if EU players are absent and medium otherwise.

Legend for the top 10 ranking:

China	EU27 countries	The USA	Other regions

Advanced manufacturing

The global industrial engineering market is dominated by Chinese and European companies[149] followed by American and Japanese competitors. **Europe stands strong thanks to very large key players in this field** especially from Germany. For instance, Siemens' recent innovation enables companies to create digital twin models of envisioned advanced manufacturing plants. Not listed in the Top10 ranking, other German companies include Bosch in advance in 3D printing[150] or Hochtief leading in the field of virtual construction and Building Information Modelling (BIM) technologies.

On the other hand, the industrial robot manufacturer market is **largely dominated by Japanese companies (e.g. Fanuc, Yaskawa)**, due to the absence of American players. European companies like ABB (SWE-SWI) compete as leading suppliers of robotic software and complete application solutions while German robot manufacturer KUKA was acquired by the Chinese group Midea in 2018.

Table 6.3: The largest industrial engineering companies, 2021

Rank	Company	Region
1	China State Construction Engineering	China
2	China Railway Engineering Group	China
3	China Railway Construction Corp.	China
4	Pacific Construction Group	China
5	China Communications Construction	China
6	Hitachi Company	Other regions
7	PowerChina	China
8	Siemens	EU27
9	Vinci	EU27
10	ACS	EU27

Source: Top largest industrial engineering companies, Insider Monkey, 2021

Table 6.4: The largest industrial robot manufacturers, 2018

Rank	Company	Region
1	Fanuc	Other regions
2	The Yaskawa Electric Corporation	Other regions
3	ABB	EU27
4	Kawasaki	Other regions

149 Largest engineering companies in the world in 2020

150 Advance Manufacturing Transformation Center (AMTC)

5	Nachi Fujikoshi Corporation	Other regions
6	Denso Robotics	Other regions
7	Midea Group (KUKA)	Other regions
8	Mitsubishi Robotics	Other regions
9	Epson Robots	Other regions
10	Staübli	Other regions

Source: Top 10 robot manufacturers, Market research reports, 2019

Advanced materials and nanomaterials

As there are a lot of advanced materials, we give below a deeper analysis of petrochemicals and carbon fibre. While European countries do not have their own raw materials, a competitive petrochemical sector is crucial for Europe as 95 % of all manufactured goods are based on petrochemicals, including electronics, furniture, appliances, textiles, and many more.[151]

Due to high input costs for petrochemicals, the EU has positioned itself in value-added markets relying on innovation and long-term relationships. The manufacture of various materials (chemical, composites) is dominated by Asians, who own half of the world's largest companies in the sector. But the leaders come from the USA and the EU, namely the American DowDuPont followed by the German BASF in the petrochemical sector and Zoltek (USA) in the supply of carbon fibre. **The EU is not a leader in the production of materials, but has powerful players and a consolidated market that cannot be ignored in each of the segments.**

The USA and EU still lead in the carbon fibre market but more Asian players have been entering the top 10 carbon fibre manufacturing ranking. The EU has the largest share of the composites segment and benefits from the rising demand for carbon fibre components in the automotive and aerospace sector. In addition to the end-user industries a growing appetite for carbon fibre is coming from emerging sectors like the wind energy sector.

Table 6.5: The largest petrochemical companies, 2021

Rank	Company	Region
1	DowDupont	USA
2	BASF	EU27
3	Sinopec	China
4	Sabic	Other regions
5	INEOS	Other regions
6	Formosa Plastics	Other regions
7	Exxonmobil Chemical	USA
8	LyondellBasell Industries	EU27
9	Mitsubishi Chemical	Other regions
10	LG Chem	Other regions

Source: Top 50 chemical companies, Chemical and Engineering News, 2021

Table 6.6: The largest carbon fibre manufacturers, 2018

Rank	Company	Region
1	Toray (Zoltek)	USA

[151] Petrochemistry applications

2	SGL Carbon	EU27
3	Mitsubishi CCFC	Other regions
4	Toho Tenax / Teijin	Other regions
5	Hexcel	USA
6	Formosa Plastics	Other regions
7	Solvay (Cytec)	EU27
8	Zhongfy-Shenying	China
9	Jiangsu Hengshen	China
10	DowAksa	Other regions

Source: Carbon fiber leadership study, Lucintel, 2018

Life science technologies

The USA leads in biopharmaceutical innovation delivering more new medicines (57 %) than the rest of the world combined,[152] thanks to a remarkable collaboration between US pharmaceutical heavy weights and innovative biotech companies and unicorns. Hence, American companies such as Amgen dominate the top 10 ranking of global biotechnology players followed by European companies and with only a modest show of new entry Chinese companies.[153]

The EU has a strong pharmaceutical sector and has seen investment in biotech firms grow significantly over the past few years. Venture Capital investments in biotech have more than doubled in some countries (Belgium). Overall, **Europe is not well represented in the top 10 ranking of pharmaceutical players and in the biotechnology sector, with the exception of the Danish company Novo Nordisk**.

Pharmaceutical and biotech companies depend significantly on suppliers of lipids, typically a critical component in vaccine production. The global lipid market is fragmented and competitive. Key players are the US companies such as CordenPharma that is a lipid provider for the Moderna Covid-19 vaccine.[154] However, the German Merck KGaA company has also contributed to the fight against the coronavirus by supplying lipids to BioNTech.

152 https://morningconsult.com/opinions/america-leads-biopharmaceutical-innovation-lets-keep-it-that-way/

153 Based on IDATE DigiWorld rankings with information extracted from multiple sources.

154 https://www.biospace.com/article/pharmaceutical-lipids-market-lipids-are-also-gaining-substantial-demand-for-developing-cancer-drug-delivery-systems/

Covid-19 vaccine development by a European biotech company

One of the promising European players in the biotech sector is BioNTech, a German company specialised in the development of immuno-oncology treatments. In 2020, ***BioNTech together with Pfizer was the first to develop a vaccine against Covid-19***. This initiative was also supported by the German government: in 2020, the German Ministry of Education provided BioNTech with €375 million to fund the company's Covid-19 vaccine development.[155] The EIB also provided funding to BioNTech, some of which already before the crisis, helping the company to developing its novel messenger RNA technology.[156] In December 2020, the BioNTech-Pfizer vaccine has been authorised for emergency use in the USA. 200 million doses are expected to be delivered to the US by the end of July 2021.[157] At the same time, EU has recently negotiated 300 million doses in addition to 300 million doses initially ordered from BioNTech and Pfizer in November 2020.[158]

Table 6.7: The largest pharmaceutical companies, 2020

Rank	Company	Region
1	Johnson & Johnson	USA
2	Pfizer	USA
3	Roche	Other regions
4	Novartis	Other regions
5	Merck & Co	USA
6	GlaxoSmithKline	Other regions
7	Sanofi	EU27
8	AbbVie	USA
9	Takeda	Other regions
10	Shanghai Pharmaceuticals Holding	China

Source: Top 10 pharmaceutical companies, Pharmaceutical technologies, 2020

Table 6.8: The largest companies in Biotechnologies, 2019

Rank	Company	Region
1	Amgen	USA
2	Novo Nordisk	EU27
3	CSL Limited	Other regions
4	Gilead Sciences	USA
5	Celgene	USA
6	Allergan (Abbvie)	USA
7	Jiangsu Hengrui Medicine	China
8	Biogen	USA
9	Vertex Pharmaceuticals	USA
10	Regeneron	USA

155 BioNTech Press Release, September 2020

156 EU financing for COVID-19 vaccine.

157 Pfizer Press Release, December 2020,

158 EU orders 300 million more BioNTech-Pfizer vaccine doses

Source: Top 25 biotechnology companies, Genetic engineering and biotech news, 2019

Micro/nano electronics and photonics

Semiconductor technology is rapidly progressing as the suppliers develop advanced products for application in different end-use industries. In 2018, memory, logic, analogue, and MPU accounted for 80 % of semiconductor industry sales with the vast majority of demand coming from laptops and smartphones.[159]

US semiconductor companies are the leading providers of microprocessors and other edge devices and maintain the leading position in R&D and process technology.[160] In 2018, they accounted for 45 % of global market share in the semiconductor industry.[161] However, the Trump administration's trade war against China has recently shifted Chinese demand (largest market for semiconductors in the APAC region) towards other global vendors.

Europe stands out for its absence in the leadership competition for electronics manufacturing. The French-Italian STMicroelectronics which is Europe's largest semiconductor chip maker and the Dutch-American semiconductor NXP remain small in comparison to giants like Intel (USA) and Samsung (South Korea).

Even though European companies do not manufacture best-in-class chips (including memory, foundry and logic), they remain in the race for supplying essential equipment (i.e. from EUV lithography and foundry and memory chips to equipment for high-end chip packaging).

On the other hand, the photonics market is very fragmented and competitive; it is mainly composed of multiple small and mid-sized companies.[162] Even though the market is dominated by Asian companies, **Europe accounts for numerous photonics companies** including large players such as Nokia but also SMEs.

Europe's competitive advantage in the global semiconductor sector

ASML produces various types of machinery such as deep ultraviolet lithography (DUV) machines and extreme ultraviolet lithography (EUV) machines that are crucial for semiconductor manufacturing. Its clients are the largest international players such as Intel, Samsung and Taiwan Semiconductor Manufacturing Co. This Dutch company is nearly a global monopolist in the lithographic equipment segment with a market share over 80 %.[163] Besides, ASML is a pioneer in the innovative EUV technology that is expected to overtake DUV machines in the upcoming years. The company is now the only one in the world supplying EUV machines.

ASML has been recently involved into the trade war between the US and China: in 2020, the company had to cancel the sale of its advanced equipment to China after pressure from the US on the Dutch government. The top-management of ASML does not expect the situation to change soon even with the arrival of Joe Biden to the White House.[164]

Table 6.9: The largest semiconductor providers, 2019

Rank	Company	Region
1	Samsung	Other regions

[159] 2019 Factbook. Semiconductor Industry Association

[160] Based on IDATE DigiWorld rankings with information extracted from multiple sources.

[161] 2019 Factbook. Semiconductor Industry Association.

[162] Photonics market by Mordor Intelligence

[163] Moody's Investors Service

[164] NL company ASML caught in the trade war between the USA and China

2	Intel	USA
3	SK Hynix	Other regions
4	TSMC	Other regions
5	Micron	USA
6	Broadcom Ltd.	USA
7	Qualcomm	USA
8	Toshiba	Other regions
9	Texas Instruments	USA
10	Nvidia	USA

Source: Top 10 semiconductoirs companies, VIPress, 2018

Artificial intelligence

In the fight for AI supremacy, China is making rapid progress whereas the USA continues its absolute lead in terms of the total number of AI players.[165] **US tech giants dominate the global market in digital services, also leading in AI software followed by Chinese** big tech companies such as Alibaba.

AI start-ups in Europe: Multiple initiatives but hard to compete with the US and China

The AI landscape in the EU counts ***around 500 start-ups mainly from France, Germany and Sweden.***[166] These companies work on applications for various industries including manufacturing, agriculture, transportation and others. European start-ups benefit from the state support. For example, in 2019 ***Bpifrance invested 368 million EUR in French companies developing AI.***[167] However, only few European start-ups that develop AI-based solutions are worth more than a billion USD. The sole AI unicorn from Europe is Meero,[168] a French-based company that uses AI and machine learning to optimise the process of photo editing. To compare, 21 unicorn AI start-ups out of 43 are currently from the USA, 12 are from China and 4 companies are from the UK.

Table 6.10: The largest AI companies, 2020

Rank	Company	Region
1	Microsoft Azure	USA
2	Amazon Web Services	USA
3	IBM	USA
4	Nvidia	USA
5	Salesforce	USA
6	Google Cloud Platform	USA
7	Alibaba Cloud	China
8	Tempus	USA
9	Automation Anywhere	USA
10	Nauto	USA

Source: Top 20 largest AI companies, Insidermonkey, 2020

165 AI Watch, TES analysis of AI Worldwide Ecosystem in 2009-2018. JRC Technical Reports

166 European AI Startup Landscape

167 Bpifrance Le Hub

168 CB Insights, The Complete List Of Unicorn Companies

Security and connectivity technologies

Despite efforts to control the handling of personal data, **Europe is absent in the cloud market as European enterprises and institutions depend on American suppliers** to protect their critical systems security. The USA largely dominates the cloud market thanks to Microsoft, Amazon, Google and IBM that jointly hold 70 % of the IaaS Cloud market.[169] The European position in cybersecurity is maintained by the French multinationals Atos and Avast which appear right after the American leaders (Norton, Cisco, McAfee) in the ranking of top 10 cybersecurity players. Also, European cybersecurity companies remain in the race thanks to the support of EU institutions in backing innovative start-ups and the overall ecosystem.

Only one sector escapes US domination: manufacturers of telecommunications products. This is led by Huawei (China) as the leading supplier with a particular focus on the deployment of 5G. As for **European companies, Nokia (FIN) and Ericsson (SWE) remain strong in the telecom equipment sector** and have been gaining more groubd in the 5G deployment race following sanctions imposed by the US on Huawei. However, they still remain behind Huawei's technology.[170]

5G deployed across the EU, but Europe is still behind Asia and North America

Europe is the third region worldwide in terms of 5G deployment, behind North America and Asia-Pacific. Yet, the state of 5G deployment is uneven between countries in the region. While Finland, Germany, Spain and Italy were among the early 5G adopters, the technology was commercially available only in 22 European countries as of the end of 2020.[171] Some EU Member States were not able to launch 5G services in 2020, as requested by the EU 5G Action Plan. Due to the Covid-19 pandemic, 5G investment will probably be delayed in Europe (and in other countries as well). However, this recent crisis can have a positive impact on the development of digital solutions in healthcare and other industries and might drive 5G in Europe in the medium and long term.

Table 6.11: The largest telecom equipment providers, 2020

Rank	Company	Region
1	Huawei	China
2	Nokia	EU27
3	Ericsson	EU27
4	ZTE	China
5	Cisco	USA
6	Ciena	USA
7	Samsung	Other regions

Source: Telcom equipment market, Dell Oro, 2020

Table 6.12: The largest cybersecurity providers, 2019

Rank	Company	Region
1	NortonLifeLock	USA
2	McAfee	USA
3	Palo Alto Networks	USA
4	Check Point	Other regions
5	TrendMicro	Other regions

[169] Worldwide Iaas Public Cloud Services Market Grew 37.3% In 2019, Gartner..

[170] Telecommunication equipment market by Dell Oro/

[171] IDATE DigiWorld, World 5G markets, December 2020

6	ProofPoint	USA
7	Avast	EU27
8	Kaspesky Lab	Other regions
9	Qualys	USA
10	F-Secure	EU27

Source: Top cybersecurity providers, Cybernews, 2019

6.2.2. Indicators not selected

Due to a lack of relevant and available indicators, notably to compare the EU with third countries, some ingredients have been left out of this study (such as research and technology infrastructures), despite their relevance for technological sovereignty as described below.

Research and technology infrastructures

Research and technology infrastructures are key for scientific discovery and are necessary to bring innovations to the market, upscaling technology and overcoming the valley of death. It includes the state of play for research and technology centres as well as academia.

Strong network of research centres in Europe

The development of research and technology infrastructure is crucial for innovation and also benefits from research funding. The infrastructure largely supports organisations in bringing projects from technological innovation to the market.

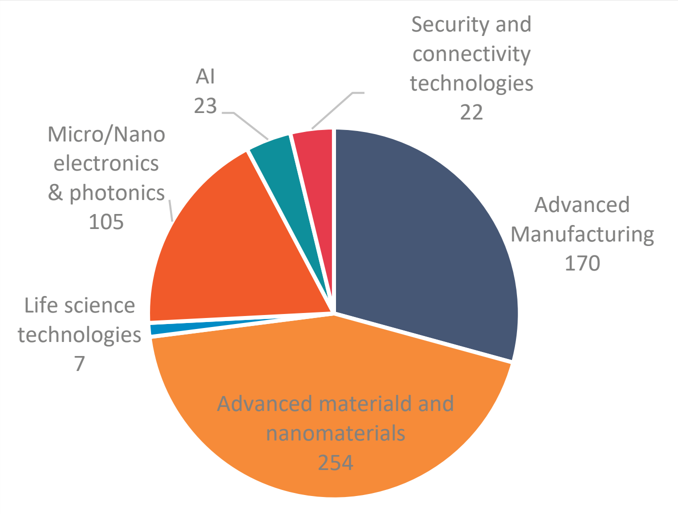
Europe has many elite research institutions including the French national research centre (CNRS), Max Planck Institute for Intelligent systems in Germany, Spanish and Italian National Research Councils that all work on a broad range of topics including multiple KETs. But, in some key areas like the life sciences KET, the USA is way ahead with different key institutions like the National Institute of Health or the Center for Disease Control and Prevention.

Beyond elite research institutions, the EU performs well in KET research thanks to its network of nearly 600 technology centres across 27 Member States.[172] These technology centres support the commercialisation efforts of other organisations. Active in the six KETs, the technology centres notably help SMEs cross the 'Valley of Death' with services from access to technology expertise to prototype development to product certification.

As regards the KETs, **advanced manufacturing and advanced materials and nanomaterials are top priority among the European technology centres**. They are core research topics for 170 and 254 research centres respectively.

[172] As benchmarked as part of Advanced Technologies for Industry (ATI) technology centers

Figure 6.4: Repartition of technology centres in Europe per KET



Source: IDATE DigiWorld, data extracted from European Commission ATI technology centres mapping

To advance the digital transformation, the EU has established **digital innovation hubs (DIHs).**[173] The network of DIHs aims to help companies to improve their processes, products and services through the use of digital technologies where the DIH act as one-stop shops for companies. DIHs also focus on improving support facilities and employment of personnel. This will allow DIHs to deliver services that stimulate a broad uptake of AI, HPC and Cybersecurity, in private and public sector organisations. Training programmes such as the DIH Enhanced-Learning Programme (DIHELP)[174] further support hubs to develop and scale-up their activities.

KET research well established at European universities

European universities cover a wide range of KETs including Computer Science, Nanoscience & Nanotechnology, Chemical, Manufacturing and Electrical and Electronic Engineering. Academic excellence is decentralised with universities in Western European and Nordic countries topping the list.

For instance, the **University of Copenhagen** (Denmark) is internationally recognised for its research excellence within all three corners of computer science (algorithms, people and data) and has leading research programmes in AI including Machine learning, Image analysis, and Programming languages. The **University of Paris-Saclay** (France) tops international mathematics rankings and is an important player in the field of quantum sciences and technologies.[175] The University of Paris-Saclay merges around 20 higher-education and research institutions and aims to become the European rival of the Massachusetts Institute of Technology (USA).[176]

At the global level, Anglo-American and European academia have traditionally led in Science and Engineering. However, **China is disrupting this and supplanting European universities which are now positioned behind those based in the United States and Asia in all KET-related fields**. In terms of research output (number of publications) in most of the KET-fields, China is at the forefront and Asia has outpaced Europe as the most represented continent by volume of publications. In terms of the global high-quality research outputs, the USA leads in terms of research

[173] Development of Digital Innovation Hubs in Europe

[174] Digital Innovation Hub Enhanced-Learning Programme

[175] Including Academic Ranking of World Universities (ARWU), QS, Times Higher Education, Multi rank

[176] On this subject, Europe has established the European Institute of Innovation and Technology((EIT) in 2008 inspired from the MIT model, based on partnerships between businesses, research institutes and universities.

output in Science and Engineering, but China has made remarkable progress largely outpacing the rest of the world including European countries as seen in the table below.

Table 6.13: Nature Index high-quality research outputs

Rank	Country	Share 2018	Share 2019	Change in Adjusted Share 2018-2019
1	United States of America (USA)	20357.17	20152.48	-4.2
2	China	11372.26	13566.11	15.4
3	Germany	4585.05	4545.7	-4.1
4	United Kingdom (UK)	3750.3	3773.66	-2.7
5	Japan	3082.69	3024.32	-5.1
6	France	2200.83	2238.55	-1.6
7	Canada	1620.19	1602.09	-4.4
8	Switzerland	1422.71	1487.88	1.2
9	South Korea	1349.94	1435.23	2.8
10	Australia	1254.34	1259.95	-2.8

Note: The Share used to order Nature Index listings is based on an institution's or country's publication output in 82 natural-science journals, selected on reputation by an independent panel of leading scientists in their fields.[177]

Source: Nature Index, Annual tables, 2020

[177] Nature Index annual tables, 2020

6.2.3. Examples of appropriate indicators

As aforementioned, there are many limitations related to currently available data in order to assess technological sovereignty. Therefore, as part of the 'KET observatory', the indicators shold be reviewed to ensure availability of reliable data. **Examples of potentially useful indicators include:**

- R&D&I funding
  - Breakdown per type of stakeholder: research centres, academics, start-up, SMEs
- Research and Technology infrastructure
  - Global ranking of technology centres
  - Number of technology centres by KET
- Innovation
  - Number of patents associated with commercialised products
- Skills/education
  - Number of job offers compared to number of STEM graduates
  - Stay rate of European PHD students in Europe
  - Foreign doctorate students as a percentage of all doctorate students
  - Adoption of digital skills (workforce, public sector)
- Market uptake
  - Start-ups acquisition by Europe companies
  - Share of European VC

6.3. Appendix 3 - Strategies and policies beyond the EU

One cannot look at the EU alone when discussing KET policies. The world is highly interconnected and decisions in one country affect others. Moreover, policies in third countries might serve as good practices. The USA is said to be better at attracting venture capital and generating start-ups while China excels in accumulating critical mass in capital and labour to support certain areas, but why is that? What are the supporting policies behind this?

6.3.1. Innovation policies in third countries

In 2019, a network of independent think tanks released a report looking at the strengths and weaknesses of innovation policies across various countries.[178] It ascertains weaknesses in the EU such as the incompletion of the Digital Single Market, a copyright system unfit for the digital age, and stagnating 2 % R&D spending of GDP short of the EU's 3 % target.[179] In the following sections, based on this report and additional sources we highlight noteworthy policies from China, Japan the USA, South Korea and Singapore in policy areas such as:

- Innovation and KET strategies
- R&D funding and improving R&D capabilities
- Private investment
- Commercialisation and market uptake
- Education and skills
- Defensive policies
- Regulations for KETs.

[178] Global Trade and Innovation Policy Alliance, *National innovation policies: What Countries Do Best and How They Can Improve*, 2019.

[179] According to the report, the EU's strengths are: 1) setting up financial instruments that support innovation (e.g. Horizon 2020, EFSI, VentureEU); 2) supporting digital government (e.g. Declaration on e-Government); and 3) agreeing on rules allowing non-personal data to move freely and easily.

Innovation and KET strategies

China excels at coordinating action across levels of government and directing its resources towards individual industries and technologies. This **comprehensive innovation framework** is summarised

Box 6.1: Made in China 2025 strategy

The Made in China 2025 strategy lays out China's ambition to win the global competition on emerging technologies. The strategy focuses on ten key sectors, some of which overlap with the EU's KETs. China's industrial policies (incl. subsidies) following out of this strategy benefited key sectors such as solar, batteries, autonomous driving and 5G and highlight the drive for competitive advantage in sectors seen as critical. In order to implement the strategy, China uses various measures:

- **Tax preferences** to incentivise foreign firms to shift production and R&D to China as well as domestic standards, IP and competition policies to transfer know-how to Chinese entities;
- **Forced joint ventures** by leveraging China's large market to press multinationals into joint ventures and transfer technology;
- **Government subsidies** that support Chinese companies in domestic R&D and overseas acquisition (as of March 2018, about 1800 funds were allocated valued USD 426 billion);
- **Foreign acquisition** supported through above mentioned funding and build Chinese capabilities to acquiring IP, talent and ties to suppliers and customers;
- **Technology licensing & equipment** to support Chinese companies in requiring needed equipment (such as semiconductor machinery) for building production capabilities;
- **Talent recruitment** in the form of encouraging Chinese expatriates to return and hiring and exchange of foreign talent.

Sources: Made in China 2025, see: http://english.www.gov.cn/2016special/madeinchina2025/; Sutter K. (2020) "Made in China 2025" Industrial Policies: Issues for Congress.

in the **Made in China 2025** strategy, which provides state-guided funds worth over €329 billion. There a subsequent action plans and strategies under Made in China 2025. Technology specific strategies exist in the area of smart cities, intelligent vehicles, AI, blockchain and big data.[180] The strategic framework is complemented by other innovation policies. For example, the 'Advice and Measures for Promoting Mass Entrepreneurship and Innovation' supports local governments in establishing venture funds, facilitating business registration and improving loan guarantees. Another supportive instruments is the Law on Promoting the Transformation of Scientific and Technological Achievements, which supports the transfer of research.

For the **USA**, the main vehicle to coordinate and move innovation forward is **Manufacturing USA**. Established in 2014 as the National Network for Manufacturing Innovation, Manufacturing USA now consists of **16 public-private partnerships** forming institutes in areas such as integrated photonics, advanced robotics, biopharmaceutical manufacturing and more. These institutes are sponsored by the U.S. Departments of Commerce, Defense, and Energy.[181] In 2019, the network conducted over 560 major applied R&D collaboration projects, engaged 1920 organisations (61 % of which are

[180] United Nations, ESCAP, *Evolution of Science, Technology and Innovation Policies for Sustainable Development: the Experiences of China, Japan, the Republic of Korea and Singapore*, 2018.

[181] For more information see: https://www.manufacturingusa.com/.

companies), helped 39,000 workers, students, and educators through training and education, and leveraged US$133 million in federal to attract US$222 million in private investment.[182]

South Korea has a history of **strong policy support for innovation**. Early on in its development, the country adopted a top-down approach supporting the emergence of large industrial groups (e.g. Samsung, LG), while shielding them from foreign competition. South Korea's early success came from subsidizing technology imports in the private sector (in contrast, Singapore was successful in technological advancement by incentivising FDI to attract foreign companies).[183] These companies established strong links with universities and technology centres in Korea and other countries. Through government-promoted R&D combined with industry investment and targeted nation-building programmes, South Korea was able to grow these companies into multinational champions.[184] For example, the government promoted the data economy through building an infrastructure for a data-driven economy including 5G and utilisation of AI. It is said that this contributed to the expansion of Korea's big data industry by 29 % in 2018. On specific technologies, South Korea has strategies and action plans for smart manufacturing (I-Korea 4.0), intelligent robots, advanced IT and AI, IoT, Fintech, Cloud computing and smart and open government.[185]

R&D funding and improving R&D capabilities

According to UNESCO,[186] ten countries account for 80 % of global R&D spending. In total volume, the USA is spending the most on R&D with about €391 billion (71.5 % of which is private funding). The USA is followed by China with US$306 billion (77.3 %).[187] Looking however at R&D spending as percentage of GDP, then Israel (4.95 %) is leading the pack, followed by South Korea (4.81 %), Switzerland (3.37 %), Sweden (3.34 %), Japan (3.26 %), Austria (3.17 %), Germany (3.09 %) and Denmark (3.06 %). The USA is ranked ninth with 2.84 % of GDP and China 13th with 2.19 % just above the EU average of 2.18 %.[188] Building such R&D capabilities depends on public (as well as private) support. For example, China's aim to develop higher defence capabilities inadvertently also led to the creation of domestic research capabilities. In other cases, foreign firms were incentivised to establish production and research (e.g. in Singapore) or research institutes were built through direct government spending (e.g. South Korea), or a mix of government subsidies enabled private sector-led development (e.g. Japan).[189]

Beyond building basic research capabilities, **China** more recently has gathered much attention for **its fast growth in R&D investment**. R&D intensity has grown from below 1 % in 2010 crossing the 2 % mark in 2013 and overtaking the EU. This success partially stems from direct research funding by the Chinese government (US$98 billion in 2017). China, however, is often criticised for its subsidies towards its national champions and their preferential access to credit, which is seen as **distorting the level playing field**. Specifically, Chinese state-owned enterprises with their strong

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182 Manufacturing USA (2020) Report to Congress. Fiscal Year 2019.

183 United Nations, ESCAP, *Evolution of Science, Technology and Innovation Policies for Sustainable Development: the Experiences of China, Japan, the Republic of Korea and Singapore*, 2018.

184 Leigh Dayton, How South Korea made itself a global innovation leader, 2 June 2020, Nature.

185 United Nations, ESCAP (2018) Evolution of Science, Technology and Innovation Policies for Sustainable Development: the Experiences of China, Japan, the Republic of Korea and Singapore.

186 UNESCO Institute for Statistics. How much does your country invest in R&D?

187 The five EU MS in the top fifteen (DE, FR, IT, ES, NL) combined invest US$235 billion in R&D. 63.3% of which comes from the private sector, highlighting a higher dependence on public funding.

188 World Bank Data. Research and development expenditure, retrieved from: https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS.

189 United Nations, ESCAP (2018) Evolution of Science, Technology and Innovation Policies for Sustainable Development: the Experiences of China, Japan, the Republic of Korea and Singapore.

financial backing can take advantage of European openness in gaining access to markets and build leadership in key sectors of the global economy.[190] While not focused on R&D, China's **Belt and Road Initiative** (BRI) should be mentioned here as well, as it provides beneficial investments to countries across the world. It is often criticised for its lack of transparency and the dependencies it creates through financial claims[191] giving China potentially preferential access to important raw materials. Moreover, international collaboration through joint research and development, technology transfer and personnel exchanges are part of the BRI action plan.

In contrast, the **USA** is often said to be driven by private investment. However, several interviewees also highlighted the important role of the US Defence budget and the close link between industry and army. The **Defense Advanced Research Projects Agency** (DARPA), with an annual budget of only US$3.5 billion, plays a remarkable role in the creation of new transformative technologies such as the internet, GPS and others. This is partially due to the flexibility granted to the agency in allocating funding. However, its success probably also stems from its close connection to the US Department of Defense's annual research and procurement budget of US$190 billion, which enables large-scale testing of successful prototypes.[192] This industrial-military complex is driven by the USA's global military presence and need for continued high investments in their armed forces to the disadvantage of civilian spending programmes.

Funding in the **USA**, also stems from procurement. A study estimated that more than US$50 billion per year is invested in **R&D procurement**. The study found that about 1.5 % of R&D procurement contracts lead to at least one patent. The study adds that procurement contracts connected to patents account for 36 % of overall contract value, but that despite the size of spending, surprisingly little research has been conducted from government R&D.[193] Finally, in the USA, the **National Science Foundation** (NSF) supports fundamental research as well as education in science and engineering in the USA. The NSF had a budget of US$8.3 billion in 2020. The foundation's focus is on the first stage in the innovation process (discovery and fundamental research).[194] It covers areas such as biological sciences, computer and information science and engineering.

Private investment

Next to public funding, high R&D intensity is driven by private investment. In **China**, surprisingly a lot of R&D comes from private investments (77.3 % of R&D spending). These have been supported by the establishment of high-tech zones, science parks, and by providing tax incentives for innovation activities. For example, in its 'patent box' scheme, China provides tax breaks for companies with a certain amount of high-skilled works, or to firms investing at least 3 to 6 % of gross revenue in R&D, or firms that generate 60 % of their revenue from IP.[195] However, as mentioned above, a lot of private investment is also driven by the preferential access to credit for private companies facilitated by the Chinese government.

South Korea's economic success is often attributed to its **high R&D intensity**. Initially this was very much driven by public funding, however today the weight of R&D investment has shifted to the private sector. Specifically, SMEs in biotechnology, AI and cybersecurity drive innovation backed by

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190 Leonard, M., Pisani-Ferry, J., Ribakova, E., Shapiro, J. and Wolff, G, [Redefining Europe's economic sovereignty](). Joint publication of Bruegel and the European Council on Foreign Relations. June 2019.

191 Ibid.

192 Nature, [DARPA 'lookalikes' must ground their dreams in reality](), 11 March 2020.

193 De Rassenfosse G., Jaffe A., Raiteri E., *The procurement of innovation by the U.S. government*, 2019, PLoS ONE 14(8): e0218927. https://doi.org/10.1371/journal.pone.0218927.

194 National Science Foundation (2010) The Role of the National Science Foundation in the Innovation Ecosystem.

195 Such a 'patent box' tax regime is also used in other countries including some EU Member States (e.g. France, Ireland). For more information see: https://taxfoundation.org/patent-box-regimes-europe-2019/.

government funding and supported by technological infrastructure.[196] South Korea provides several government incentives to companies in various areas. Specifically for R&D, Korea has a hybrid system consisting of tax credit for R&D expenditure and credit for investment in R&D equipment. For example, there is a **R&D tax credit for SMEs**, accessible to SMEs that meet annual sales revenue and asset value thresholds and engage in R&D activities. It can be used for labour costs, materials costs, rent for R&D equipment, training and more.

South Korea's tax credit is supplemented by measures such as **patent box incentives** (tax exemption for SMEs that transfer or lease patent rights to a Korean party) and a **tax credit for investing in facilities for research and testing**. There is also a specific **tax credit for investing in new technology areas**, which supports companies investing in the commercialisation of new technologies.[197] This credit is applicable to 233 technologies covering twelve areas.[198] Finally, **foreign companies** in certain key technologies can apply for a five-year exemption from acquisition tax and property tax.[199] OECD estimates show that Korea's system favours SMEs with a marginal tax subsidy rate of 0.26 (OECD median: 0.19) compared to large firms' marginal tax subsidy rate of 0.03 (OECD median: 0.14). Between 2007 and 2017, business R&D intensity increased in Korea from 2.29 to 3.62 % and in 2017 Korea was the fourth highest OECD country in terms of government support to business R&D (0.31 % of GDP), after Belgium, France and Russia.[200]

In **Japan,** in 2019 about 84 % of government support for R&D came from tax incentives. In 2020, the country updated its **tax credit for special open innovation R&D expenses**. The updated open innovation tax incentive promotes the investment of company internal reserves into venture companies, allowing them to deduct 25 % of venture investment for their taxable income. The minimum investment should be JPY 100 million in a Japanese or JPY 500 million in a foreign company. The aim is to increase the supply of funding to venture companies which are seen as key to innovation.[201] It also incentivises joint or contract research with universities and national research institutes. Combined with already existing tax incentives, companies can obtain a maximum of 45 % (60 % for start-ups) of tax credits for corporate tax liability. After the tax reforms first establishing the open innovation incentive in 2015, tax credit usage has been increasing from JPY 300 million (2014) to over JPY 3,900 million (2015) to JPY 8,400 million.[202] SMEs and large companies have access to similar levels of tax subsidies, with the former having an estimated R&D tax subsidy rate of 0.20 and the later of 0.17.[203] With 0.15 % of GDP, Japan is slightly above the OECD median in terms of government support to private sector R&D.[204]

Commercialisation and R&D uptake

A key strength in the **USA**, are its **policies supporting technology transfer and commercialisation** of federally funded R&D. The Bayh-Dole Act from 1980 has been instrumental

[196] Leigh Dayton, How South Korea made itself a global innovation leader, 2 June 2020, Nature.

[197] Deloitte (2020) Survey of Global Investment and Innovation Incentives. South Korea.

[198] These are: Futuristic vehicles, intelligence information (e.g. AI), software or security, electronic information devices, broadcasting communications, bio-health, energy, environmental, convergence materials, robotics, aerospace and advanced materials/parts/equipment. For more information, see: Rap Choi, U. (2020) 'Korea expands R&D tax credit, other technology tax incentives', 11 February, MNE Tax. Available at: https://mnetax.com/korea-expands-rd-tax-credit-other-technology-tax-incentives-37643.

[199] Deloitte (2020) Survey of Global Investment and Innovation Incentives. South Korea.

[200] OECD, 'R&D Tax Incentives: Korea, 2019', 2019, Directorate for Science, Technology and Innovation.

[201] BDO, *New "Open innovation tax inventive"*, World Wide Tax News, Issue 55, June 2020.

[202] EY, Japan tax alert. R&D tax credits under the COVID-10 pandemic: Promises and pitfalls, 2020.

[203] This relates to profitable companies, as loss-making companies to not receive any R&D tax incentives.

[204] OECD, 'R&D Tax Incentives: Japan, 2019', 2019, Directorate for Science, Technology and Innovation.

in this success as it gave the rights to IP stemming from federally funded research to participating universities, small businesses and non-profit institutions. The Act is said to have resulted in the market uptake of much federally funded research. A study estimated that between 1996 and 2015 GDP the Bayh-Dole Act contributed to US$591 billion in GDP growth.[205] Similar laws were passed in countries such as Germany and Japan. However, the law has been criticised for turning research culture away from science towards profit. This is said to hurt fundamental research and lead universities to fiercely protect their findings instead of cooperating and granting access to other researchers. For example, lawsuits between researchers and universities over patents have become commonplace.[206]

Next to the Bayh-Dole Act, the **Small Business Innovation Research** and **Small Business Technology Transfer Research** programmes are said to also have contributed to an effective research and technology transfer environment. Together, they provide about US$2.5 billion annually to support commercialisation of R&D generated by small businesses. Past recipients of support include companies such as 23andMe, Apple and Qualcomm. Finally, **strong IP right protections** in the USA contribute to the commercialisation of research. IP rights are enshrined in the US constitution and are considered as a catalysator for America's innovation system,[207] however IP rights are often also seen as overrated in the digital age and the EU IP system is not too different.

In **South Korea**, market uptake is supported by a system of **regulatory sandboxes**, first introduced in 2019. Such sandboxes provide for a more flexible regulatory framework facilitating the testing and deployment of innovation. The sandboxes cover all industries. In 2019, 195 sandbox projects had been approved in areas such as self-driving vehicles, phishing prevention, and blockchain services. Many of these applied for exemptions to requirements stemming from personal data protection rules.[208] In addition, a public-private sandbox support centre was set up as a bridge between authorities and companies, which can review and approve applications for time-limited regulatory exemptions.[209] Thanks to this, new technologies such as wireless charged e-buses and autonomous delivery robots have been introduced for testing on Korea's roads.[210]

Education and skills

The success of countries such as China, South Korea, Japan and Singapore stems also from actively building human resources aligned with their broader R&D policy objectives. For example, Japan focused on expanding science and technology in higher education to increase the number of engineers and scientists, while Singapore founded technical training institutes to have a workforce able to support high-value-added industries.[211]

More recently, in 2018, the **South Korea** introduced **software education** across all levels of education and promotes the creation of science and technology focused programmes. The National Programmes of Excellence in Software, launched in 2015, has the goal to make Korea a society powered by software, starting with basic software education from elementary to high school and

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205 Lori Pressman et al., *The Economic Contribution of University/Nonprofit Inventions in the United States: 1996–2015*, Report prepared for AUTM and Biotechnology Industry Organization (BIO), June 2017, 3.

206 Loewenberg S., The Bayh–Dole Act: A model for promoting research translation?, 2009, *Molecular Oncology* 3, 91-93.

207 Global Trade and Innovation Policy Alliance (2019) National innovation policies: What Countries Do Best and How They Can Improve.

208 One Trust Data Guidance, South Korea: FSC releases reports on regulatory sandbox development, 2020.

209 The Korea Herald, Regulatory sandbox support center launched, 12 May 2020.

210 Pulse, Unwired e-buses and robots allowed on roads in South Korea, 24 September 2020.

211 United Nations, ESCAP (2018) Evolution of Science, Technology and Innovation Policies for Sustainable Development: the Experiences of China, Japan, the Republic of Korea and Singapore.

going on to encourage students to take software classes regardless of their majors.[212] In addition, Korea aims to increase the number of software-centred universities.

In 2019, **China's Education Modernisation 2035 Plan** was introduced. The plan aims for China to enter the ranks of the most powerful countries in terms of education by 2035. Specifically in regard to innovation, it aims to upgrade first-class talent development and innovation skills, and accelerate education reform and innovation in the era of ICT. It also links with the BRI, through the BRI's aim to train international talents, and by improving policies for Chinese oversea students to return to China.[213] Building on the plan, China set out guidance improving China's online education infrastructure by using the internet, big data and AI more widely in education. Covid-19 is said to have accelerated these efforts (e.g. through the launch of a national cloud classroom platform). Specifically on AI, China has been encouraging universities to engage in greater international collaboration on AI and for students to study abroad in countries with good quality level research on AI. Postgraduate education in AI was further promoted in 2020 through a communication by the Ministry of Education. In addition, over 100 new majors in AI technology across Chinese universities were approved.[214]

Defensive policies

Access to markets and exporting are critical for business, especially in knowledge-intensive industries. A major market for European companies in past decades has been **China** and vice versa. Exports to China are an important contributor to Europe's high value-added sectors and thereby generate skilled jobs in Europe. Similarly Chinese exports contribute to value chains and competition in the EU. In recent years, this trade has increasingly been driven by direct investments with Chinese companies targeting access to technology and brand reputation. However, unfair treatment remains a serious problem for European companies.[215] EU regulations are much less discriminatory, while for example Chinese ownership policies force European companies into joint ventures (e.g. between 2000 and 2017, 55 % of investment by German vehicle manufacturers was in joint ventures), in the EU equitable treatment allows Chinese companies to hold controlling ownership stakes.[216]

Box 6.2: EU – China Investment agreement

The recently agreed upon **Comprehensive Agreement on Investments between China and the EU** aims to address imbalance in the EU-China trade relationship. Specifically, it aims to improve market access for EU investors, ensures fair treatment for EU companies, notes China's obligations in the treatment of state-owned enterprises, transparency of subsidies, and has rules against the forced transfer of technology. According to the European Commission, the agreement sets a high benchmark in terms of transparency, level playing field, market access commitments and sustainable development.

Source: European Commission (2020) EU and China reach agreement in principle on investment, see https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2541

212 Gachon University (2018) Department of Software wins and runs the National Software Programme in Software for Gachon University.

213 Zhu, Y.,*New National Initiatives of Modernizing Education in China*, 2019, ECNU Review of Education, Vol. 2(3) 353–362.

214 Australian Government. Department of Education, Skills and Employment, China's education modernisation plan towards 2035, 2020.

215 Bauer M. and Lamprecht Philipp (2018) Investment Openness in Europe: Investment Screening and Implications for EU-China Investment Relations.

216 Ibid.

In late 2018, the **USA** updated its legislations on **export control** and **investment screening** in order to address concerns of technology diffusion, in particular to China. The Export Control Reform Act (ECRA) and the Foreign Investment Risk Review Modernization Act (FIRRMA) have similarities to the EU's proposed modernisation of its export controls to cover sensitive dual-use goods and technologies and the new EU framework for the screening of foreign direct investment, although their reach goes beyond what is done in the EU. In particular, ECRA gives the executive extensive discretionary powers to limit or ban exports and makes the process to obtain export licenses for critical technologies more restrictive. It also established an interagency review process to identify emerging technologies currently not covered by export controls. FIRRMA strengthens the authority of the US Committee on Foreign Investment (CFIUS) widening the range of transactions it can take actions on to include non-controlling investments in US firms that are engaged in critical technologies.[217] Some 10 % (24 transactions out of 237) were stopped in 2017 compared to 8 % (18 out of 229) in 2018, and 3.5 % (8 out of 231).[218]

The USA has also been active in combatting **science espionage**. In 2015, the FBI launched an awareness campaign targeted at companies. It informs companies about how to defend against economic espionage by highlighting actual cases and explaining how to protect one's trade secrets.[219] However, recent reports about investigations into alleged Chinese spies also shows how such increased scrutiny could possibly harm scientific and economic collaboration as researchers are worried about being targeted by federal investigators for accepting grants from China or collaborating with Chinese universities.[220]

6.3.2. Conclusion

There is a wealth of third country examples of policies enabling, regulating or protecting innovation in KETs. The above text highlights some noteworthy examples, however more examples across the separate areas can be found in the sources mentioned throughout the text.[221] Moreover, with the fast pace of technology, new strategies, policies and regulations are always in the making. Policy-makers in Europe need to be aware of these as they could impact innovation and economy in the EU or serve as possible blueprints for new policies in the EU.

217 Leonard, M., Pisani-Ferry, J., Ribakova, E., Shapiro, J. and Wolff, G., Redefining Europe's economic sovereignty. Joint publication of Bruegel and the European Council on Foreign Relations. June 2019.

218 White & Case, CFIUS Update: Proposed Changes to Critical Technology Mandatory Filing Requirements; 2018-2019 Statistics Show Key Trends, 28 May 2020, CFIUS Implements New Case Management System.

219 FBI, Economic Espionage. FBI Launches Nationwide Awareness Campaign, 2015.

220 See for example: Nature, US investigations of Chinese scientists expand focus to military ties; Future Human, The U.S. Crackdown on Chinese American Researchers Endangers the Future of Science, C&EN, 70 years of US suspicion toward Chinese scientists—and what those caught in the middle should do now.

221 For a comprehensive overview the following two sources can be recommended for further reading:

United Nations, ESCAP, *Evolution of Science, Technology and Innovation Policies for Sustainable Development: the Experiences of China, Japan, the Republic of Korea and Singapore*, 2018.

Global Trade and Innovation Policy Alliance, *National innovation policies: What Countries Do Best and How They Can Improve*, 2019.

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Technological sovereignty has been at the heart of recent political debate in the EU. Interest has only been strengthened by the Covid-19 pandemic crisis, due to its impact on many value chains.

Key enabling technologies (KETs) – advanced manufacturing and materials, life-science technologies, micro/nano-electronics and photonics, artificial intelligence, and security and connectivity technologies – are crucial for an interconnected, digitalised, resilient and healthier European society, as well as being important for the EU's competitiveness and position in the global economy.

This STOA study analyses how the EU is performing in developing and protecting ownership and know-how in these critical technologies, especially in comparison with strong global players such as China and the USA. Based on the challenges identified in the analysis, it discusses policy options for strengthening the EU's technological sovereignty in KETs.

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