Challenges for European Science and Technology Driven Innovation in Europe

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Background:
An Euro-CASE working group (WG) was set up with the intent to identify opportunities to better link research to technological innovation in Europe for the post-Covid period. This work follows up on a "pre-Covid" report on the potential and limitations of Open Science for academia and technology that was prepared by the Royal Academy of Sciences, Arts and Letters of Belgium, and published in English and French[1]. The WG stabilized to a core set of nine members (including three female members), that includes professionals with managerial and political experience, from business, industry, academia, government and regulatory bodies, both in Europe and the USA, who:

- Work in Belgium, Croatia, France, Germany, Poland, Spain and the USA,
- Are all fellows of one or more national engineering and/or science academies, including a member of a "young" academy[2], and collectively are Fellows of eight academies: Royal Academy of Science, Arts and Letters of Belgium (Class of Technology and Society and Class of Sciences), Academies of Science of France, Hungary, Norway, Poland, and Turkey, Islamic World Academy of Sciences (an organ of OIC which is an organization of the United Nations) and Academia Europaea.

The WG met frequently for some nine months (one online meeting approximately every two weeks). Several external speakers from Europe and the USA were invited to make presentations. Each chapter of the report was written by one or two WG members, and edited and refereed by other WG members.

An "in person" workshop was held in Paris in September 2021, with several Euro-CASE board members (and others) attending online. A list of recommendations was written, discussed and edited jointly by the whole WG.

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[1] Gelenbe, Erol, Brasseur, Guy, Chefneux, Luc, Dehant, Veronique, Halloin, Veronique, Haton, Jean-Paul, Judkiewicz, Michel, Rentier, Bernard, Weikmans, Romain. On Sharing Knowledge and Fostering "Open Science". May 2021, Association for Computing Machinery, New York, NY, USA, https://doi.org/10.1145/3462221

[2] The academies to which the WG members belong include the Royal Acad. Sci. Arts and Letters of Belgium, the National Academy of Technologies of France, the Royal Academy of Engineering of Spain, the Science Academies of France, Hungary, Norway, Poland, Turkey, Academia Europaea, Islamic World Academy of Sciences.

The WG members are:

Guy Brasseur, Foreign Fellow of the Royal Academy of Sciences, Arts and Letters of Belgium (RASALB) and of the Norwegian Academy of Sciences, holds two engineering degrees in physics and in telecommunications and electronics, and a PhD on photochemistry and transport in the middle atmosphere, all from Univ. Libre de Bruxelles, Belgium. He was elected to the Belgian House of Representatives (1977-81) and later returned to a scientific career that has included substantial management duties. Appointed Director of the Atmospheric Chemistry Division at the National Center for Atmospheric Research (NCAR), Boulder, USA, (1990-2000), he became Director at the *Max Planck Institute for Meteorology* and Scientific Director of the *German Climate Computer Center* (2000). Coordinating Lead Author for the fourth Assessment Report (WG-1) of the *International Panel for Climate Change* which received the Nobel Peace Prize 2007 jointly with Al Gore, he was Associate Director of NCAR, Head of its *Earth and Sun Systems Laboratory* (2006-09), and founding Director of the *Climate Service Center* (CSC) in Hamburg. He now heads the Environmental Modeling Group at the *Max Planck Institute for Meteorology* and is the first *NCAR Distinguished Scholar*.
Luc Chefneux, Fellow of the RASALB, holds an engineering degree in physics, a PhD in metallurgy and a degree in economics and management from Univ. of Liège, Belgium. He is also honorary Lt-Col of the Corps of Engineers. Expert of the steel industry, he most recently served for 12 years at ArcelorMittal Global R&D as (successively) Director of Scientific and International Affairs (2005-12), Director of Open Innovation and Knowledge Management (2013-15), and Director of International Partnerships and European Affairs (2015-17). He then served as technical advisor on Innovation for the Minister in charge of Economy and Industry in Wallonia (2017-2018) and as Vice-Director then Director of the Technology and Society Class of RASALB (2018-2021).
Veronique Déhant, Fellow of RASALB, is an astronomer and Head of the Operational Directorate "Reference Systems and Planetology" at the Royal Observatory of Belgium. Her research focuses on the detailed dynamics of planetary systems. She is also a Foreign Fellow of the French Academy of Sciences, has won ERC grants and served on ERC panels.
Anna Fabjańska, a member of the Young Academy of Poland (2016-21), was awarded her M.Sc., Ph.D., and D.Sc. (habilitation) degrees in computer science by the Faculty of Electrical, Electronic, Computer and Control Engineering, Lodz University of Technology (LUT). Associate Professor at the Institute of Applied Computer Science at LUT, and member of the Committee on Informatics of the Polish Academy of Sciences, she works on computer vision, including machine learning and AI, with dedicated image processing pipelines for scientific, industrial and biomedical vision systems. Beneficiary of a scholarship for outstanding young scientists (2013-15), and a START Fellowship from the Foundation for Polish Science in 2011, manager of a project within the "Iuventus Plus" program (2013-15), she also won a Professorial Scholarship from LUT.
Erol Gelenbe, Fellow of NATF and the Turkish Science Academy, Foreign Fellow of RASALB and of the Polish Acad. of Sciences, Hon. Fellow of the Hungarian and Islamic World Acad. of Sciences, Fellow of IEEE, ACM, IFIP, IET and the RSS, he is Professor, Institute of Theoretical and Applied Informatics, Polish Academy of Sciences. He received the BSc (METU, Ankara), MSc, PhD in Electrical Engineering (Tandon School, NYU, USA), the D.Sc. in mathematical sciences, Sorbonne, Paris, and works on the performance, security and energy consumption of computer systems and networks. He was Professor of Computer Science successively at the universities of Liège, Belgium (1974-79), Paris-Saclay (1979-86), Paris-Descartes (1986-93), Scientific Director at INRIA (1973-83), Lecturer at Ecole Polytechnique, Paris (1980-87), adviser to the French Minister for Universities (1983-86). He was Head of Department, Electrical and Computer Engineering, Duke University, USA (1993-98), Director of the School of Electrical Engineering and Computer Science and Associate Dean of Engineering, University of Central Florida, USA (1998-03), and Dennis Gabor Chair, and Head of Intelligent Systems and Networks, Imperial College, UK (2003-19). His work has been supported by NSF, EPSRC (UK), DoD (USA), MoD (UK), the EU, and European, US, and UK industry, and is currently supported by the EU H2020 Program, UKRI, as well as industry.

Véronique Halloin, former Professor and Department Head of Chemical Engineering, and former Vice-Rector for Research at ULB (Brussels), she is President of the European Science Foundation, and Secretary General of FNRS, the Belgian National Research Fund. She serves on many boards in industry, academia and at CERN.
Michel Judkiewicz, Fellow of RASALB an engineer with a M.Sc. from Univ. Libre de Bruxelles, Belgium, also holds several certificates in business and industrial management from INSEAD and the University of Houston. He has served recently as Secretary General of EIRMA, the European Industry Research Management Association (2010-14) and as Managing Director of CCLJ, Brussels (2017-20). He is currently Managing Director of Silver Brains, Brussels (since 2014).
Vladimir Mrša, Fellow of the Academy of Engineering of Croatia, received his Ph.D. in Biochemistry from the Faculty of Science, University of Zagreb in 1984. He joined the Laboratory of Biochemistry, Faculty of Food Technology and Biotechnology, University of Zagreb in 1980 and has been Professor at the same Faculty since 1999. He has conducted research in the field of protein glycosylation and secretion, as well as cell wall biosynthesis in fungi. An active member of the Croatian Society for Biochemistry and Molecular Biology, Croatian Microbiological Society and Croatian Society for Biotechnology, he served as Dean of the Faculty of Food Technology and Biotechnology, University of Zagreb (2003-07), where he is now Head of the Department of Chemistry and Biochemistry, and Editor-in-Chief of the journal Food Technology and Biotechnology.
Ignacio J. Pérez-Arriaga, Fellow of the Royal Acad. of Engineering of Spain and Life Fellow of IEEE, *Professor and Director of the BP Chair on Sustainable Development*, Instituto de Investigación Tecnológica (IIT), Universidad Pontificia Comillas, Madrid, Spain, received his MS and PhD in Electrical Engineering from MIT, and the Electrical Engineer degree from Comillas University. He is Visiting Professor at the Center for Energy and Environmental Policy Research, MIT, USA (2008-present). Founding director of IIT for eleven years, he was Commissioner, Spanish Electricity Regulatory Commission (1995-2000), independent member of the Single Electricity Market Committee of Ireland (2007-12), member of the Board of Appeal, EU Agency for the Coordination of Energy Regulators (ACER), Director of Training at the School of Regulation, European University Institute, Florence, Italy, and review editor of the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Consultant and lecturer in more than 30 countries, author of several books and more than 200 papers, he was principal investigator in over 90 projects, and supervisor of 35 doctoral and over 100 master's theses. His current research includes future trends in energy regulation, regulation and planning of electricity access, regional markets, and operation and planning of power systems with strong presence of renewable generation and decentralized resources.

Executive Summary[3]

In 2020 the GNP of the United States, the European Union (EU) and China amounted to $20.8bn, $15.3bn and $14.7bn, respectively. Europe with 7% of the world's population produced 21% of the world's scientific publications, ahead of the USA and matching China. But in 2020, among the twenty largest technology brands in terms of capitalization, one was European, with four Chinese companies and one Korean company. Among technology companies ranked by revenue, of the top twenty, only one was European. In 2020, among the top 50 companies by revenue, only 6 were European, while European venture capital deals accounted for 13% , against 50% for the USA, of an estimated $270 billion total venture capital deals across the world. These indicators, which included the UK as being within the EU for 2020, warn us that despite its history, culture, quality of life and size of its population, Europe must make further efforts to transfer science into technology, innovation and

[3] This report contains data which are mostly publicly available, and can be found in Reports or Websites published by Governments, the EU, or well-known national or international agencies; we have provided references in many of the cases where the data is cited in the text. However, the current economic instability, possible changes in government policies, and modifications voted by parliaments in response to proposals by governments, can affect the accuracy of the data.

business. This report identifies some of Europe's challenges in this respect, and recommends new initiatives to improve science and technology driven innovation in Europe.

The first chapter of this report aims to identify the **Paths and Stumbling Blocks from Research to Innovation in Europe.** Indeed, whereas research and innovation are key elements for assuring economic prosperity and tackling most of the dramatic challenges that humanity faces, our limited human, financial and natural resources require that we undertake the drive from research to innovation in an efficient and organized manner. We need to identify the main stumbling blocks so that corrective actions may be undertaken, and we must obviously benchmark ourselves in comparison with the world's other big economic players, which are both our partners and competitors, such as the USA, China, and other countries that are ahead of us such as Korea and Japan. The strides made closer to us by other players such as Israel and Turkey, and our interactions with neighbours in Africa, the Middle East and Eurasia, cannot be ignored. Chapter 1 summarizes the stumbling blocks that Europe's innovation ecosystem faces via an Ishikawa diagram, which also includes the means we may have to improve and accelerate the opportunities for technology transfer and innovation in Europe. Some of the improvements that are identified include the need to better fund applied goal driven research and development that can help us transition from the Technology Readiness Levels 4, 5, and 6 where research outputs are tested under simulated conditions, towards TRL levels 7 and 8 where system prototypes are should be tested under realistic operating and market conditions. At the end of TRL 6, projects enter the critical “Valley of Death”, where most of them may sink due to a lack of financial support for pilot demonstration. The few projects that cross this step will need funding from enterprises or individuals that take the financial and commercial risk of taking the innovation to market. In the manufacturing industry, the costs are typically multiplied by a factor of 10 at each TRL stage. In these critical stages Europe is far less successful, in particular as compared to the USA. To overcome these stumbling blocks, industry-university-business joint doctoral research, research and technology organizations operating at the border between academia, business and industry, technology campuses combining higher education institutions with industrial development and production units, the active presence of venture capitalists, and pre-competitive government funding and tax incentives, all have a role to play.

Chapter 2 analyzes the organizations that the EU has set up to foster applied research, innovation and the commercial exploitation of research and innovations. It identifies internal duplication between organizations, frequent changes in rules and regulations, programs targeted to specific organizations which upset the level playing fields, with some programs funded at such low levels that they cannot attract the best proposals. It reviews the existing structures and identifies some of the opinions of the end users about the structures and programs that are launched by the EU to foster applied research and innovation. The chapter pleads for a European innovation eco-system modelled as a "rainforest" where species die, and others are born in a constant creative recombination mechanism, without prejudice and “likes” or “dislikes”, and clear "physical-chemical-biological rules" that avoid biases, lack of trust, interest, power games, short term policies, etc.. It recommends that “transaction costs” (such as studies, negotiations, decisions, follow up, verifications, red tape, etc.) should be minimized to enhance the focus, intensity and ease of cooperation among stakeholders. The chapter recommends shortening social distance, breaking up of hierarchies and bureaucracy, easing and speeding up connections. Successful behaviours should be generalized with team spirit and multi-disciplinarity, celebrating success, tolerating failure and enhancing the ability of stakeholders to rebound from failure with improved proposals and better ideas**.**

Chapter 3 examines **the European Union's Support for Basic Research** which brings a critical mass of public resources to make European research, business and industry more competitive, and benefit society at a level which cannot be achieved via individual national organizations. The best known program deployed by the EU is the bottom-up driven ERC (European Research Council), focusing on basic research at the frontiers of knowledge since 2007, that funds exploratory, ground-breaking, high-risk/high-gain research of Europe's best researchers via Starting, Consolidator, Advanced Grants, and Proof of Concept or Synergy Grants in all research fields (Life Sciences, Physical Sciences and Engineering, Social Sciences and Humanities). Excellence of the proposals is assessed by high-level international peer review panels that aims to identify the best ideas by the "best brains" in Europe and attract non-European talents. The projects aim at scientific breakthroughs or major advances, and in some cases, at bridging the gap between pioneering research and innovation. While these programs, as we as others such as CERN, have undeniably demonstrated their value in basic science and research in general, their impact on innovation has so far been limited. The ERC has become one of the world's most important funders of basic research, with high credibility in the scientific community. The overall ERC budget from 2021 to 2027 will total 16 billion euros, and represents 17% of the overall budget EU Horizon. Since its creation, the ERC has acquired an enviable and prestigious reputation. It has funded, with expenditures so far of 20.5 billion euros, just over 10,000 lead researchers plus 75,000 other research or administrative staff, in 891 host institutions belonging to 38 countries. On the other hand, the 2100 patents and 400 or start-ups the ERC program has fostered so far represent a potentially small return on investment, although (according to some sources) about two-thirds of the ERC are expected to have an economic impact in the medium to long term. Obviously, most ERC grantees can expect a sudden decrease in funding at the end of their ERC grant, since such levels of funding cannot easily be matched by national or industry sources. These considerations would suggest that additional measures may be needed to encourage the development of innovations that can arise from such a massive investment.

Chapter 4 addresses the important element of the innovation infrastructure of any modern economy: the European Universities that create knowledge and support innovation. Yet Europe has long benefited from large research organizations (CNRS, Max-Planck Gesellschaft, EMBO in fundamental biology, CNR and INFN in Italy, CERN, INRIA, etc.) and research and technology organizations (RTOs) such as Fraunhofer, CEA, VTT in Finland, IMEC in Belgium, etc. Moreover, with 7% of the world's population (in 2020) it produced 21% of the world's scientific publications, ahead of the United States and matching China (21%), but the majority of Nobel Prizes have been awarded for many years to researchers with PhDs from the United States that also recruits Nobel laureates from other countries. Unfortunately, European industry also invests less in research than its counterparts in the US and China (but more than its counterparts in Japan). Technology-based industrial and economic developments in the United States and Asia are supported by major investments in science, technology and higher education, while Europe's investments in research over the past three decades has lagged. Indeed, the sums committed are sometimes insufficient, the bridges towards innovation at higher TRL can improve, administrative constraints are excessive, and base funding for Europe's higher education is limited as compared to our major competitors.Yet a recent reports acknowledge the role of universities and SMEs in European innovation, stating that "70% of high potential innovations are co-developed by universities; collaboration between universities and SMEs appears to be particularly successful, and new products are co-developed ... often in collaboration(s) involving universities ", as in the United States where university know-how results in "start-ups" by academics and doctoral graduates. Indeed, the critical value of universities collaborating with both start-ups and large companies was dramatically demonstrated by the Covid19 vaccines. Two of them in Europe are the result of university teams: Biontech in Germany by Turkish-born Prof. Uğur Şahin of the University of Mainz, Dr Özlem Türeci and their team, and the Astra-Zeneca vaccine by Prof. Sarah Catherine Gilbert of Oxford. The American Moderna vaccine and the Biontech vaccine are both based on the Hungarian-born pioneer Prof. Katalin Karikó's work. So, we see that Universities can offer unprecedented solutions to major challenges, just as in the 1980s Universities launched the great "catching up" in Informatics,that was underestimated at the time in Europe, but is now recognized as being crucial.

However comparing Germany to the USA, the Goethe Institut states that: "Expenditure on higher education has increased overall in Germany; ... but per student spending is still below the OECD average. Germany spends around $9,000 per student, while ... in OECD countries it is $10,200 ... the UK spends almost $16,000 per student, and the USA as much as $21,000. Germany has fallen behind ... : most higher education costs there are covered by the state, the finance ministry stumping up 86% of the total. 57% of tuition costs in the UK is paid by the state, while the figure is a mere 32% in the USA. In other words, students there ... shoulder a much greater share of their university expenses." These sums represent base funding and do not include research income in Germany, the UK or the USA. Indeed, Germany the most populous and largest economy in the EU. If we also examine the public research budgets received by Universities, the USA NSF budget for Fiscal Year 2021, which represents only 25% of the Federally funded research in USA universities, was $8.45 bn, while Federally funded university research budgets in USA Universities totaled $33.9bn. The USA Department of Energy Laboratories, contributed $35 bn more to US Federal research expenditures in 2020, without including the research from more applied DoD agencies and the Department of Commerce (e.g., NIST with over $1bn), or SBIR ($3.2bn), or STTR ($450m) in recent years. Funding from NASA, DARPA/ARPA and NIH should be included in the $33.9bn Federal research funds spent annually by USA universities. These sums cannot be compared with the €3.77 bn annual budget of the Helmholtz Association, the €0.9 bn annual subsidy for Fraunhofer (roughly 30% of its income), and the €1,92 bn budget of the Max Planck Society, totaling €6.6 bn or $7.25 bn (at $1.1 per euro). Comparing per capita, with the USA population being nearly four times larger than that of Germany, and taking the Federal funding of university research in the USA plus the Dept. of Energy national laboratories for a total of $68.9 bn, dividing by four we have $17.2 bn (not counting US Defense R&D), as compared with the $7.25 bn annual income of Germany universities for publicly funded research: we observe a 230% (17.2/7.25) superiority of the USA with regard to Europe's economically most powerful nation. Adding the yearly average over seven years 2014-2020 obtained by Germany from H2020 (most of these sums are received by Research and Technology Organizations (RTOs) and industry, but we add the €1.27 bn per year for Germany to the calculations), we see that the USA research funding superiority as compared to Germany, corrected for population size, becomes "only" 198% (17.2/8.65). Thus substantial efforts must be undertaken on behalf of universities throughout Europe to strengthen their research base and allow them to compete at the best international level.

Main Recommendations

<u>A) Strengthening Industry-University-Research Interactions (all sums that are estimated to include at most 20% overheads)</u>

A1) Funding of 10,000 Competitive I-BUD (Industry-Business-University Doctoral Fellowships, similar to French CIFRE), at +2000 per year over 5 years.

Total estimated <u>steady-state cost</u> 10,000 x 250,000 = 2.5B Euros (including 20% overheads) with joint EU-Industry-Business Funding

A2) Initial funding for 100 new RTOs across Europe at +20 per year over 5 years.

Total estimated one-time cost 5M x 100 = 500M Euros (one time, spread over 5 years with no overhead included). It is expected that these RTOs will be launched with matching funds from local or national governments, and possibly industry and business.

<u>B) Strengthening the EU University Research Base</u>

B1) Seeding 50 European University Endowments through EU+Private+State Funds at 300M Euros (total of which 100M from EU) per EU Endowed University, at +10 per year over 5 years.

Total estimated one-time cost 50 x 100M = 5B Euros (no overhead included). The 3-5% annual return on these funds (circa 10-15M euros/year) will allow the selected universities to seed of the order of 10 research chairs or research centers each year, and improve their research excellence and reputation.

C) Accelerating transfer from Horizon Research and Innovation to Industry & Business

C1) Competitive Support for 1000 Horizon R&I and ERC Projects to reach TRL 6/7/8 across Europe, at +200 per year over 5 years.

This should be a means to follow-up on those projects whose outcomes have been identified as being particularly promising for innovation. The total estimated steady-state cost is 1M x 1000 = 1B Euros.

D) Developing fiscal incentives for cross-EU investments in technology start-ups

D1) Providing 1000 Competitive Fiscal Support Stimulus Packages (European Start-Up Equalization Fund) to European Start-Ups at +200 per year over 5 years.

Total estimated steady-state cost 1000 x 1M = 1B Euros (no overhead included). This can be coupled with C1.

D2) A legislative and financial equalization of inter-EU start-up investments is needed. The objective is to assure that taxation aspects of EU investments in innovation can be incentivized independently of the fiscal residence (which EU country) of the EU investors and the fiscal residence of the EU innovative companies that receive the investments.

E) We propose that a "Responsible Innovation principle" should be introduced to counterbalance the "Precautionary principle"

1. Paths and Stumbling Blocks from Research to Innovation in Europe

by Luc Chefneux

It is universally considered that research and innovation (R&I) are key elements for assuring economic prosperity and tackling most of the dramatic challenges that Humanity is facing. Furthermore, the natural limitations in human, financial and natural resources require that the efficiency with which we address these objectives must be continuously pursued.

The ambition of this report is to identify the best paths for reaching this efficiency, which also requires the identification of the main stumbling blocks so that correcting actions are undertaken. While our main scope is Europe, our continent must obviously be considered and benchmarked in comparison with the world's other big economic players, which are both our partners and competitors (USA, China), and with other countries that are particularly ahead in these domains sch as Korea and Japan. However the strides made closer to us by other players such as Israel and Turkey as well as our interaction with our neighbours in Africa, the Middle East and Eurasia, cannot be ignored.

First of all, let us attempt to define the concepts which will be discussed further so as to facilitate the discussion so as to avoid confusion.

The OECD's Frascati Manual[5] offers the following definition: "*Research and experimental development (R&D) comprise creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledg*e ... *R&D covers three types of activity: basic research, applied research and experimental development.* ***Basic research*** *is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.* ***Applied research*** *is original*

[5]Frascati Manual 2015 https://www.oecd.org/publications/frascati-manual-2015-9789264239012-en.htm

investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. ***Experimental development*** *is systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing."*

In the Oslo Manual[6], it is stressed that Innovation goes far beyond R&D: *"It goes far beyond the confines of research labs to users, suppliers and consumers everywhere – in government, business and non-profit organisations, across borders, across sectors, and across institutions."*[7] The definitions are related to industrial and marketable innovations only:

- A ***product innovation*** *is a new or improved good or service that differs significantly from the firm's previous goods or services and that has been introduced on the market.*

- A ***business process innovation*** *is a new or improved business process for one or more business functions that differs significantly from the firm's previous business processes and that has been brought into use by the firm."*

Obviously, though we are focused on such kinds of innovation, many other kinds of innovation do exist based or not on science or technology, but on administrative, organizational, educational, social aspects.

The OECD definitions are useful for the measurement of the different kinds of activities allowing international comparisons, but they don't identify the actors and processes. But they do not explain the so-called European paradox*: "EU is excellent in basic research but does not take economic profit of the developed knowledge.* Another approach can better explain this fact by differentiating two complementary processes, with their key players.[8]

Figure 1 illustrates the fact that the pathway from basic research to innovation involves many actors and is not a simple linear one. At the bottom of this figure, basic research process which can be free or oriented, is presented. Basic research is developing new knowledge, without any or direct application in view. It is typically one fundamental mission of universities. In Europe, some other institutions are sharing the same mission, as the CNRS[9] in France or the Max Planck Society in Germany to name a few. This new knowledge, more and more open to the world (Open Science movement, spreading knowledge as soon as it is available, using digital and collaborative technology), can take a very long time before leading to a practical use on the market. Let us think at the history of laser! At the top of the figure, the innovation process is directed towards specific objectives. At its early stage, applied research closely linked with experimental development is using existing knowledge. Different kinds of actors are participating: academic teams very often involved also in oriented basic research, research and technology organisations (RTO) making the link between universities and enterprises, and some enterprises themselves having devoted R&D centres.

Of course, the two processes are closely connected or intricated. It is particularly the case for oriented basic research and applied research in universities, while the distinction between both has more a didactic purpose. To better understand the role of the different actors, it is also important to introduce the concept of "Technology Readiness Level" (TRL) which is presented on Figure 2. It is an important tool for understanding the importance of the contributions of different players in the R&I

[6] Oslo Manual 2018 https://www.oecd.org/sti/oslo-manual-2018-9789264304604-en.htm
[7] https://www.oecd.org/site/innovationstrategy/defininginnovation.htm

[8] "Why innovate? What are the challenges for Europe?", Luc Chefneux, Académie royale de Belgique, *https://academie-editions.be/accueil/315-why-innovate-what-are-the-challenges-for-europe-.html*
[9] Centre national de la recherche scientifique, https://www.cnrs.fr/

processes.[10] It allows to see that there is a long way before reaching the highest TRL levels allowing companies to develop new market, remembering that the strength of a chain depends of its weaker link!

Oriented basic research is the seed of future innovations, developing new solutions at TRL1 and 2. In the early stage of the innovation process, from TRL3 to TRL 5(6), the Engineering Schools play a significant role, as do some enterprises, but the main role is played by RTO's making the link between universities and enterprises.

At the end of this stage, the projects are entering in the most critical part of their life, the so-called "Valley of Death", where most of them are sinking due to a lack of the financial support for building pilot equipment and then demonstration lines. The few projects crossing this step will finally need enterprises taking the financial and commercial risks for deploying the innovation on the market. In the manufacturing industry, the costs are typically multiplied by a factor 10 at each step, passing from successful applied research to pilot phase, then to industrial demonstration. It is clearly in these critical phases that Europe is less successful, particularly than USA.

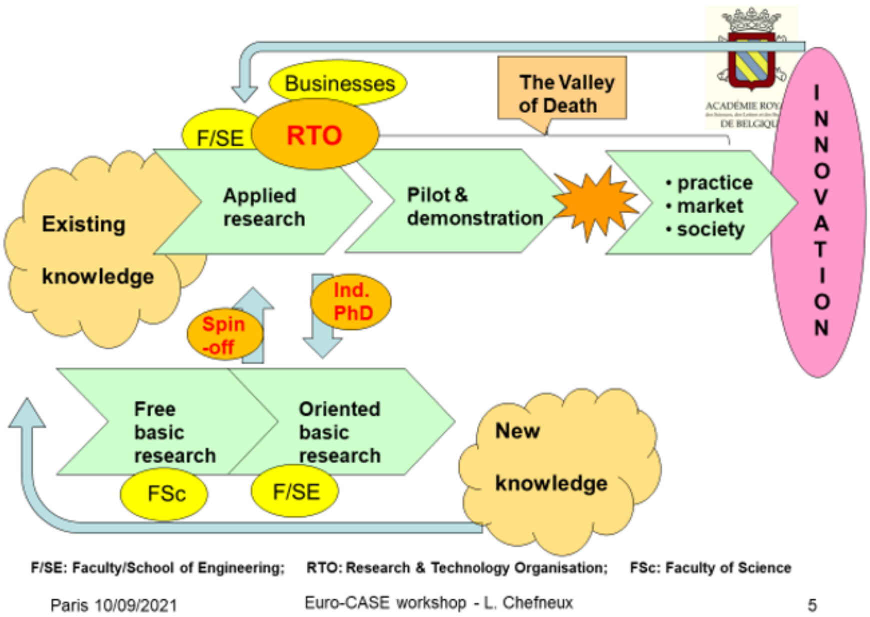

Fig. 1

[10] https://en.wikipedia.org/wiki/Technology_readiness_level

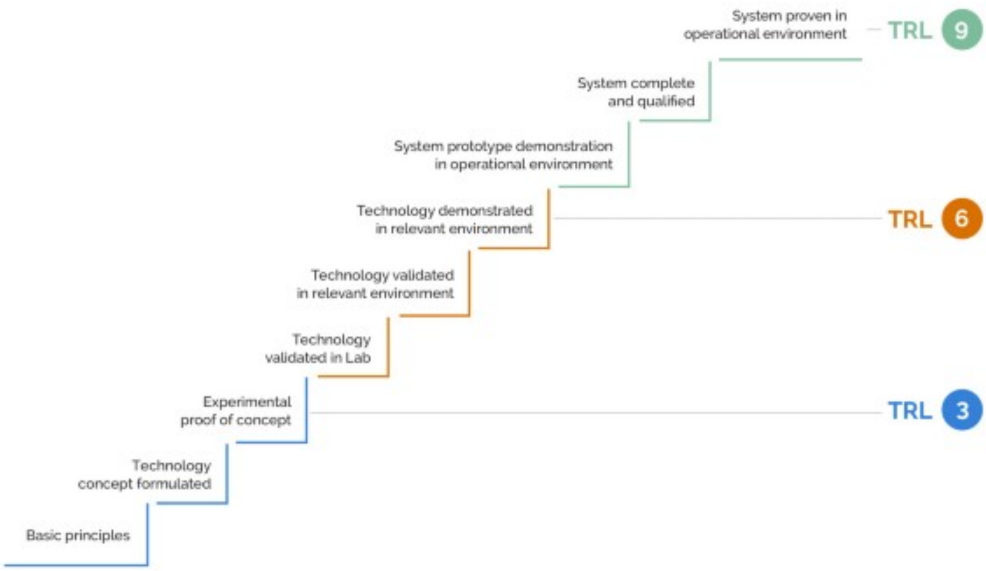

Fig. 2

Let us now better identify the challenges that R&I are facing in Europe, with some generic needs and pathways for by-passing the stumbling blocks. These points will be examined with more details in the different chapters of this report.

If we can consider that Europe is still at the top of basic research, we can't rest on our laurels! The financial support for European universities is significantly less than in USA or UK, which could lead to a progressive lagging in basic research and to a progressive decrease of the education level. But quality of education, which is also a fundamental mission of universities, and excellence in research attracting international high-level students, are the breeding ground where innovation projects will grow.

Financing universities constitutes a huge challenge for the European Union in general and for each Member State (MS) or Region having different levels of wealth! Some of the European Union programs are performing very well like the ERC Grants and would need even more financial support favouring bottom-up approach for excellence. But we are far from the necessary seeds to allow the next necessary steps. Anyway, some large universities can be considered as top "Research universities", depending of their financial resources, excellence level and international audience. Nevertheless, all universities have to play the same role at their level, which can be local, regional, national or international.

The new Horizon Europe program will play an important role for supporting excellent science, inter alia, by the European Research Council funds. An aspect which must be stressed is the fact that, as far as basic research is concerned, the scope is the world. New knowledge developed is more and more directly freely disseminated at world level, a tendency clearly accelerated by the open-science trend.

On the contrary, while the market in which an innovation will spread is also global, the innovation process is local, either at European Union (EU), Member State or regional levels. The EU policy intends to develop mechanisms to support innovation by creating European eco-systems that encourage innovation, R&D and entrepreneurship[11], for being competitive against USA or China but

[11] https://ec.europa.eu/regional_policy/en/policy/themes/research-innovation/

also by fostering good practices in MS and Regions, in which the public authorities will also support their own eco-systems of innovation.

To cross the so-called "Valley of Death", it takes time, equipment, finance, devoted organizations and human resources and perhaps the most important, proximity links and confidence among all the players.[12] It is the reason why, research campuses (Scientific or Technology Parks) are developed closely linked with universities. There is the place where spin-offs and other start-ups can find the needed support to live and grow, especially in the fields of new technologies, as Information and Communications Technology (ICT), Artificial Intelligence (AI), biotechnologies and many others. Spin-offs emerging from universities or RTOs as well, are playing an important role for supporting seeds of breakthrough innovations or for pushing and diffusing rapidly new emerging technologies, by-passing the slow classical practices.

Some big industries having strong R&D resources can also find a great interest having a location in such a campus. They are able to take directly profit of the university research, even at a very low level of TRL, and obviously of the proximity of start-ups. It is typically the case of companies of the pharmaceutical and biotechnological sectors, as of the ICT field. However, it is not the case for companies which are in more classical sectors as manufacturing and generally speaking for SMEs. They need to have at their disposal devoted applied research centres, allowing them to develop innovations at intermediary levels of TRL, from TRL4 to TRL7.

It is the key role of RTOs, which are in closer contacts with the companies, better knowing their needs and where pilot equipment, mutualized in many cases, can be implemented. These organisations are actually playing a key role in the innovation process in Europe, attracting important funding from EU R&I programs, at least at the same level than universities if basic research is not considered.

Many European countries have initiated such kind of applied research centres a long time ago, few years after the second world war. These centres which are commonly not-for-profit organisations (NPO[13]), can have diverse stakeholders, being professional associations, governments, public-private foundations and of course private companies. MS or Regions where such RTOs are well developed are clearly the best performers in EU, e.g. Germany with Fraunhofer, Finland with VTT, The Netherlands with TNO, Basque Country with TECNALIA or Flanders with IMEC and VITO. All information can be found in the website of EARTO[14], the European Association of Research & Technology Associations.

To illustrate the importance of such organizations well developed in the most innovative European MS, it is significant that USA started to follow this model. Despite the excellence of the research universities and the importance of public institutes as NIST[15], this model has been considered as important to be implemented, especially for the competitiveness of the manufacturing industry.

In 2012, during the first presidency of Barack Obama, inspired by the Fraunhofer Association model considered as the benchmark, a first centre is launched in the field of additive manufacturing. It was the flagship Institute for the National Network for Manufacturing Innovation.

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[12] https://www.uk-cpi.com/blog/the-innovation-challenge-and-the-valley-of-death#:~:text=%20The%20Innovation%20Challenge%20and%20the%20Valley%20of,the%20information%20and%20thoughts%20gained%20during...%20More%20

[13] https://en.wikipedia.org/wiki/Nonprofit_organization

[14] https://www.earto.eu/

[15] https://www.nist.gov/

“Manufacturing USA” was created to ensure that the U.S. will continue to be a leader in global manufacturing into the future. Manufacturing USA does this by fostering collaborative development of advanced manufacturing technologies through 16 manufacturing innovation institutes and their sponsoring federal agencies, the U.S. Departments of Commerce, Defence, and Energy.[16]

All these institutes are gathering federal agencies, universities and a lot of big, medium and small companies. In 2020, the institutes supported over 500 major applied R&D projects involving more than 2,000 different organizations, providing them with advanced manufacturing workforce development and training. All these institutes are focused on a specific technological field.

A key condition for the efficiency of these organisations is the close proximity (location and institutional links) with universities but with an independent legal status! Good practices can be identified: RTO members giving lectures at the university as invited professors, academic seconded staffs in RTOs, doctoral candidates performing their thesis inside the RTOs etc. When all these components can be located in a same open campus, it is the ideal situation as personal contacts and links are very important for generating ideas and cooperation. Nevertheless, it is not always possible and it is the main strength of competitiveness clusters organized at regional levels, bringing altogether components of the innovation process, destroying the walls of the different silos existing between universities, applied research centres and companies, which are so detrimental in creating innovation ecosystems, key condition for success! Intellectual property rights would be acknowledged, based on legal framework for a constructive way of working.

However, such an approach can also be implemented for supporting and fostering innovation on specific societal challenges, needing also complementary competencies and societal approaches beyond technology aspects. A good example in Europe can be found in the circular economy of metals, with the “Reverse Metallurgy” ecosystem.[17] A very important mechanism for supporting the innovation process inside companies, the big ones as the smallest, is the doctorate in enterprise (or Industrial PhD). When an enterprise is open to recruit or to support a doctoral applicant, in strong collaboration with a university, possibly and additionally with an RTO, for solving a basic problem, it is clearly an indicator of a strong potential interest, in a pull approach. The best example of this practice is the French CIFRE program[18], initiated in 1981, providing every year more than 1500 new contracts.

Some European Members or Regions have understood the strong interest of this system, while numerous are still ignoring it or reluctant due to an obsolete conception of the doctorate.[19] Coming back to the quote of the Oslo Manual *“Innovation goes far beyond the confines of research labs to users, suppliers and consumers everywhere – in government, business and non-profit organisations, across borders, across sectors, and across institutions”,* it is necessary to identify the many conditions allowing the efficiency of the innovation process. For the clarity of the presentation, it was decided to present these by an Ishikawa diagram, presented in the Figure 3, which should be a frame for thinking.

[16] https://www.manufacturingusa.com/pages/advanced-manufacturing-technology-leadership
[17] http://www.reversemetallurgy.be/en/index.html
[18] https://www.enseignementsup-recherche.gouv.fr/fr/les-cifre-46510
[19] The percentage of new doctors (STEM) is the first KPI in the” European Innovation Scoreboard” https://ec.europa.eu/info/research-and-innovation/statistics/performance-indicators/european-innovation-scoreboard_en

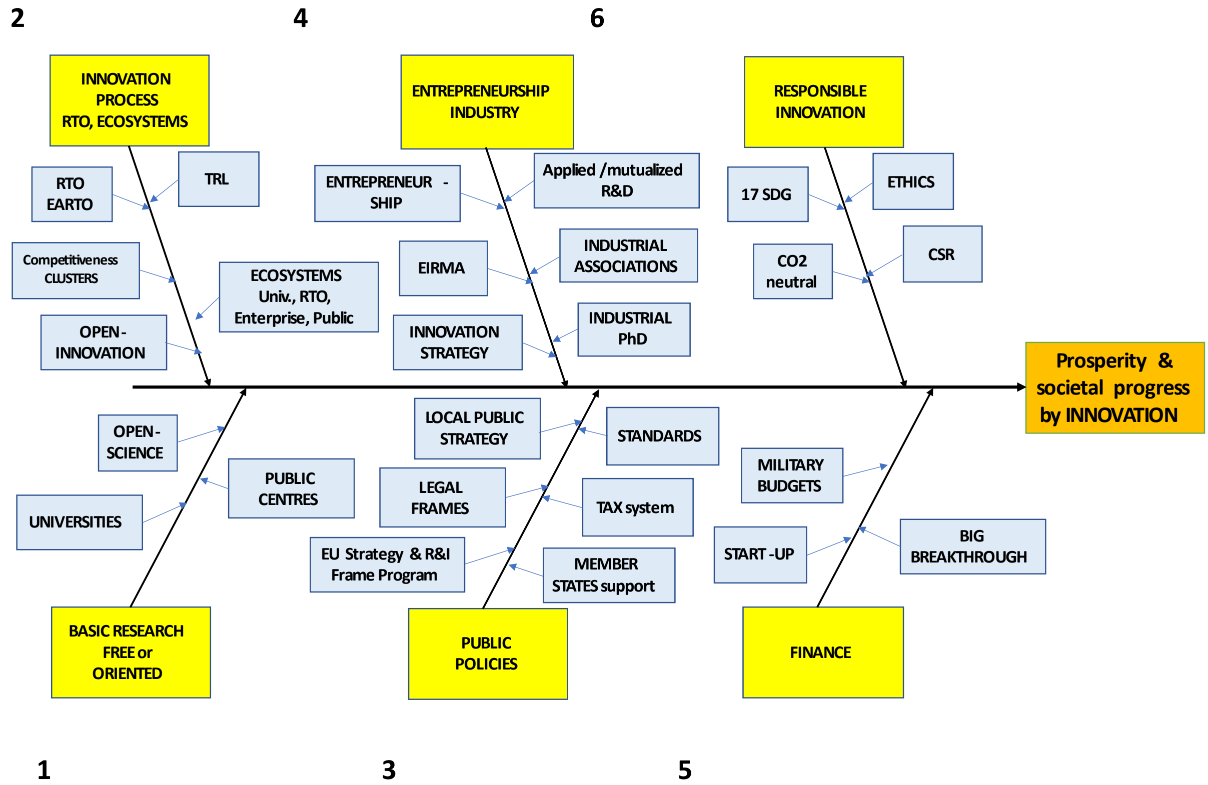

Fig. 3

Representing all elements is not possible, as it will be impossible to address all of them in this report. However, defining different categories of contributions to the efficiency of the innovation process would allow all interested persons to build his/her own global view of this systemic issue and to think about the main challenges to tackle for improving his/her specific situation.

1. Basic Research, free or oriented: A strong support from public (mainly) and private sources should allow Europe to remain at the top of knowledge creation.

2. Innovation process, RTOs, ecosystems: A special attention is to be paid to the ecosystems of innovation, especially to the devoted organisations (RTOs, clusters), in order to be able to profit of our competences and knowledge, resolving definitively the European Paradox.

3. Public policies: At their different levels, EU, MS, Regions have to develop a strategy, to adapt their legislations, to create an environment fostering innovation and to adapt their funding and tax policies, without omitting the importance of imposing EU standards.

4. Entrepreneurship & industry: Maintaining and redeveloping a strong industrial base in Europe is mandatory for having a strong innovation.[20] All enterprises, big and small, have to develop innovation strategies, being supported by associations, and having the possibility to create synergies with basic research through Industrial PhDs. It requires an entrepreneurship culture which has to be developed along the education cursus and an involvement of industrial partners for the training of young researchers.

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[20] "Manifesto. The de-industrialization of Europe. There is no more time to lose!" Académie royale de Belgique https://fr.calameo.com/read/000339428c5409493ed87

5. Finance: The key is obviously finance. Beyond the public money which is important, actions have to be developed to attract finance for all promising initiatives, from start-ups to big breakthroughs. Let us mention for completing the picture the importance of military budgets in the USA and China, which are contributing to develop advanced dual use technology[21] in a close manner.

6. Responsible innovation: This concept has to be taken into account in all projects. It is no more acceptable to support or accept any innovation which will be detrimental to the Society and could hamper the objectives of sustainable development. But as any innovation could be misused, follow-up processes should be implemented. Many other things could be added to this picture: quality of education system, attractiveness of STEM (Science, Technology, Engineering, and Mathematics) orientations, Intellectual property rights, standards, cultural aspects etc. The discussion is open!

[21] https://en.wikipedia.org/wiki/Dual-use_technology

2. Improving the European Union's support for Technological Research and Start-Ups by Michel Judkiewicz

2.1 Preliminary: state of R&D and Innovation: **from "Scale up Europe manifesto", 2016** [22]

"Europe has no shortage of successful entrepreneurs and innovative ideas. In fact, contrary to the clichés bandied about, Europe boasts more entrepreneurs per capita than the United States, a country generally taken as a benchmark for entrepreneurial excellence. The problem, however, is that European companies seldom grow to scale. Far too many remain two-person, three-person, or quite often just one-person companies. Their innovative ideas remain the exclusive domain of local economies, sometimes confined to a single European Union member state, sometimes even to a single region within them. They fail to take on the global heft and job-generating scale of well-known U.S. start-ups, such as Apple (founded in 1976), Amazon (1994), Google (1998), Tesla (2003), Facebook (2004) or more recently Uber (2009). This is why Europe urgently needs a new initiative – a Scale Up Europe movement. We must create a better, more fertile environment where our undoubtedly brilliant, creative entrepreneurs can build the global champions, create the jobs, develop the "next big thing" and deliver the prosperity our society will demand in years to come. Arguments that Europe lacks an entrepreneurial spirit or has some DNA-rooted fear of risk are categorically wrong. To the contrary, Europeans have shown that we are outstanding entrepreneurs, capable of thriving even in policy environments that sometimes do little to incentivise growth or encourage innovation. And, while policymakers have undoubtedly made progress in creating ecosystems to help people with ideas to turn them into companies, there remains an evident gap in the next steps of development: the growth phase, where imaginary visions grow into large, powerful, multinationals – with sales in many markets, and products that define the cutting edge of the economy of tomorrow.

Put simply, policymakers and stakeholders urgently need to improve the conditions not just for launching start-ups, but for growing companies, and ultimately for "internationalising" their activities as the most successful enterprises eventually do. We urgently need to rally around a broadly-held consensus – a trackable roadmap – uniting start-ups, policymakers, entrepreneurs, think tankers and citizens alike around a set of concrete, actionable items. This roadmap should be drawn up (as this manifesto has been) based on best practice throughout the 28-member European Union – and beyond. **And it should be philosophically based and emotionally rooted on a two-part strategy: embrace the future – and deliver".**[23]

Needless to say, the EU is generating an important multi-billion € budget to support Research and Innovation. Part of that budget is devoted to promote support for technological research and start-ups, transforming the results of R&D into innovation, i.e. products and/or services that generate value and, as a feedback, will help invest in R&D in a virtuous circle.
A central issue is to examine the efficiency of that support mechanism.

1- Organizational chart of R&D Directorate at the EU: a complex structure with different entities

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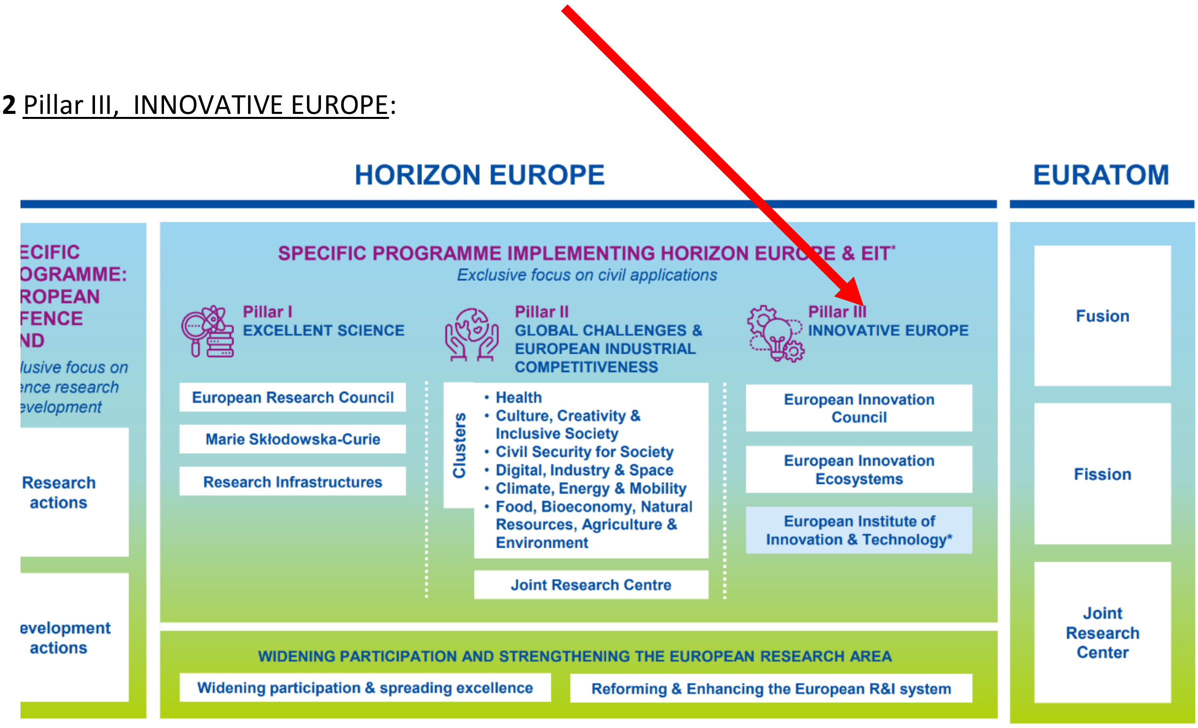
[22] https://lisboncouncil.net/wp-content/uploads/2016/09/SCALE-UP-EUROPE.pdf
[23] https://lisboncouncil.net/summits/scale-up-europe-a-manifesto-for-change-and-empowerment-in-the-digital-age/

The EU has generated, over time, different entities that, like the nodes of a network, interact in a sometimes **complex constellation**. Some of those specific instruments even depend on different directorates as not all of them are part of the Directorate General Research & Innovation that launches **Horizon Europe**, the next EU research and innovation framework programme 2021-2027. After nearly seven years of planning, and three years of intense political negotiations among the EU member states, its **€95.5 billion budget** has been approved. The programme is an umbrella for different entities with specific purposes. Let us quote the following list: ERC, JRC, EIT, ERA, EIC, … **We shall focus on the <u>pillar number III of the Directorate</u>**. (Pillar I is "excellent science", Pillar II is "global challenges and European industrial competitiveness").

2.2 Pillar III, INNOVATIVE EUROPE:



* The European Institute of Innovation & Technology (EIT) is not part of the Specific Programme

It is meant to be **stimulating market-creating breakthroughs and ecosystems conducive to innovation**: European Innovation Council **(EIC)**, **connecting** with regional and national innovation actors and European Institute of Innovation and Technology (**EIT**), **bringing** key actors (research, education and business) together around a common goal for nurturing innovation[24]
EIC (depending on Directorate Research and Innovation): the European Innovation Council is a support to innovations with breakthrough and disruptive nature and scale up potential that are too risky for private investors.

Launched in March 2021 with a budget of more than €10 billion for 2021-2027, the European Innovation Council aims to be a **one-stop-shop for innovators**. It provides support from the early-stage scientific research on breakthrough technologies, to transitioning research results into commercial opportunities, and the development and scaling up of innovative start-ups and SMEs. EIC encompasses the following (source EU):
- **EIC pathfinder:** R&I grants (from early technology to proof of concept)
- **EIC accelerator**: Grants & investment (via EIC Fund) for single SMEs & start-ups
- **EIC transition:** R&I grants (proof of concept to pre-commercial)
- **European innovation ecosystems:** European Innovation Ecosystems actions are grouped under two categories: **CONNECT** and **SCALEUP**.

C**ONNECT** focuses on building interconnected, inclusive innovation ecosystems across Europe, including the green, digital, and social transitions. **SCALEUP** focuses on reinforcing network connectivity within and between innovation ecosystems to accelerate sustainable business growth. European Innovation Ecosystems also supports the **European Partnership for Innovative SMEs**

Business acceleration services: Under Horizon Europe, the EIC support funding aims at accelerating EIC innovations and growth of top deep tech companies. These services are available through the EIC Community platform or provided through the **EIC Fund** or partner organisations. [25]

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[24] https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/presentations/ec_rtd_he-investing-to-shape-our-future.pdf
[25] https://eic.ec.europa.eu/eic-funding-opportunities/business-acceleration-services_en

EIT (Depending on Directorate Education and Culture): the European Institute of Innovation and Technology (EIT) is an independent EU body strengthening Europe's ability to innovate. The Institute is a EU initiative that drives innovation across Europe by bringing together organisations from business, education and research and find innovative solutions to global challenges.

Are EIT and EIC 2 complementary bodies or are there some overlaps? In any case, a **MOU (**Memory of Understanding) has been signed between those 2 bodies, depending on 2 different general directorates[26]. Other complementary initiatives include the **Industry strategy**, **SME cooperate and innovate**, **Digital Europe strategy, European Research Area, …**

The incoming administration could decide to redesign the directorates. **For now though, "EIT is with one commissioner (Education and Culture), EIC is with another commissioner,**" said Jean-EricPaquet,[27] "But our strategic planning means this is not a difficulty," he said.
Critics of the move to create the EIC say that it risks significant overlap with the EIT, launched in 2008. A key negotiator for Horizon Europe, MEP Lieve Wierinck predicted in 2018 that the EIC would eventually supplant the EIT.[28] The entry of a new player comes as the EIT tries to move beyond criticism that it is too bureaucratic and a drain on EU money.

2- Procedures for project participation: simplification: Still a high burden for SME's!

The Commission has definitely simplified and refined the procedures for project participation. Yet, it remains a serious roadblock for SME's, given the residual complexity. [29] As a matter of fact, some private companies have specialized in helping candidates to prepare the request for project participation.

3- ENIRI study [30]

A comprehensive several years study about R&D & Innovation efficiency in Europe, published in 2017, was done by Bird & Bird, a lawyer company, with a panel of international experts (including EU person, universities, industrialists, industry association, consultants…).

On 7 April 2017 the European Commission published the final report on the study on "State aid support schemes for RDI in the EU's international competitors in the fields of Science, Research and Innovation".
The study, which was commissioned by the Commission's Directorate-General for Research and Innovation and conducted by Bird & Bird, is the most comprehensive analysis of the EU state aid rules on research, development and innovation (RDI) support ever undertaken by the European Commission. It was triggered by concerns that these rules may be threatening the competitiveness of European industry.
The study involved in particular a comparison of public RDI support in the EU and in 9 non-EU countries (Australia, Brazil, Canada, China, India, Japan, Russia, South Korea and US), a detailed analysis of real-life cases regarding RDI investments of European companies outside the EU and of non-European companies in the EU as well as a comprehensive review of the EU state aid rules and their application in the period 2008 to 2015.

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[26] https://eit.europa.eu/library/memorandum-understanding-between-european-institute-innovation-and-technology-eit-and-dg
[27] https://ec.europa.eu/info/persons/cv-jean-eric-paquet_fr
[28] Old EU innovation body 'will be eaten' by new one, says MEP | Science|Business (sciencebusiness.net)
[29] "What's new in Horizon Europe": The Science|Business summary16 Jun 2021 | News
[30] https://ec.europa.eu/programmes/horizon2020/sites/default/files/full_einri_final_study_report.pdf

The study concludes that existing EU state aid rules on RDI support are overly restrictive and do not take sufficient account of the particular nature of RDI activities. It finds that:

- **Public RDI support in the EU is less effective than in Japan, South Korea and the US** due to the complexity of the EU rules, the way they are being implemented and the long duration of the EU approval process.
- **The EU state aid rules on RDI support do not take into account the particular challenges and needs of SMEs** and provide insufficient incentives for collaboration between SMEs and universities/ research centres.
- **The transparency requirement (which does not exist in the 9 non-EU countries) harms beneficiaries of RDI support** since it provides competitors with detailed information on the research undertaken by the beneficiary.
- **The presumption that aid threatens to distort competition may not be appropriate for RDI support**.

Based on these findings, the report makes a number of policy proposals, which include:

Increasing the thresholds triggering an obligation to notify RDI aid to the European Commission;
Reducing the number of permitted aid intensities from 30+ to 2;
Limiting the scope of the transparency requirement;
Expanding the notion of 'Important Programmes of Common European Interest';
Shortening and simplifying the approval process (e.g. limiting the review process for cases raising serious issues to 5 months);
Transferring the power to approve support for RDI under the EU state aid rules from DG Competition to DG Research & Innovation.

When Bird & Bird presented the report to the Council of Ministers in March 2017, the report's conclusions generated significant interest. For an abstract of the study see: [31]

Some discussions were still ongoing in 2020 for **"Important Projects of Common European Interest" (IPCEI)** [32] see below in:

AIDS GRANTED BY STATES *Article 107*

… any aid granted by a Member State or through State resources in any form whatsoever which distorts or threatens to distort competition by favouring certain undertakings or the production of certain goods shall, in so far as it affects trade between Member States, be incompatible with the internal market…

The following may be considered to be compatible with the internal market:
aid to promote the economic development of areas where the standard of living is abnormally low or where there is serious underemployment, and of the regions referred to in Article 349, in view of their structural, economic and social situation;
aid to promote the execution of an <u>Important Project of Common European Interest or</u> to remedy a serious disturbance in the economy of a Member State; [33] yet right now, the application is still very limited to a few cases like microelectronics and battery chain value.

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[31] pages 6, 7 of https://ec.europa.eu/programmes/horizon2020/sites/default/files/full_einri_final_study_report.pdf

[32] https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659341/EPRS_BRI(2020)659341_EN.pdf

[33] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.C_.2016.202.01.0001.01.ENG&toc=OJ%3AC%3A2016%3A202%3ATOC

4- Rainforest versus structured ecosystems and Europe's structured Ecosystem

In 2019, the following report was published: "A Robust Innovation Ecosystem for the Future of Europe Report on the Results of the Stakeholder **Consultation October 2019 – February 2020"** [34] . **One reads the following:** "**This report presents the result of a consultation process launched by the Commission with representatives of innovation ecosystem stakeholders, start-ups, investors, corporates, universities and Research & Technology Organisations (RTOs), regions, and cities, national innovation agencies and ministries. The goal of the collected information is to help build the future of the innovation ecosystem in Horizon Europe2**, the next funding programme for Research an Innovation, in the most inclusive, diverse, and connected way possible. Each ecosystem stakeholder has specific bottlenecks and challenges related to issues of connectedness, competence and talent… The challenges are grouped in three major pillars: connectedness of the stakeholders, competence and talent, and capital. Some challenges and actions belong to all three and are treated as crosscutting challenges. **According to the feedback and survey data collected, connectedness between stakeholders, both locally and abroad, is one of the critical challenges for many stakeholders.** This connectedness between all stakeholders must be sustained not only nationally, but across borders, where new coordination tools must be developed, suitable for Europe's incredible diversity and ecosystem complexity. **…** Beyond these three challenges, stakeholders brought up **the urgency to reduce the current regulatory burden. There is a need for simplified legislation, experimentation and flexibility of existing legislation."**

An innovation ecosystem such as Silicon Valley is modelled like a rainforest [35] where species die, and others are born in a constant creative recombination mechanism. There are little "likes" or "dislikes" in the rainforest, only physical-chemical-biological rules that maintain a dynamic equilibrium, unlike our human society where a number of biases do exist: emotions, lack of trust, interest, power games, short term policies, etc.

As the 1991 Nobel prize economist Ronald Coase, following the work of John Kenneth Arrow (Nobel prize 1972) outlined, there is a "**transaction cost"** (studies, negotiations, decisions, follow up, verifications, red tape, etc) that is highly impacted by the level and ease of cooperation of all the stakeholders. [36] **Clearly, this cost is much lower in Silicon Valley than in Europe**. It is all about shortening social distance, break up hierarchies and bureaucracy, easy and quick connections, generalization of successful behaviours. Team spirit, challenge, some adventure, friendship, co-opetition, multi-disciplinarity, confidence, sincere success celebration and tolerance for failure, as learning experiences, become the keywords. **The rainforest paradigm: a dynamic, quickly interacting network to seize opportunities, allow emergence, bifurcation and pivoting, seems to be the best ecosystem.**

5- Recommendations for improvement

From the different studies and analysis above, a way for the European research and innovation to be on a par with the "best in class" regions of the world would encompass a global modification of the current process that is mostly top-down, towards a more bottom-up approach, i.e.

1- Decrease the current number of programs currently eligible for aid and open up for researchers' creativity and ingenuity to come up with research projects

[34] https://www.earto.eu/wp-content/uploads/A-robust-innovation-ecosystem-for-the-future-of-Europe.pdf
[35] The Rainforest, the secret to building the next Silicon Valley, Victor W Hwang, Greg Horowitt, Regenwelf 2013
[36] Innovation, effet de mode ou nouvel équilibre, D.M. Judkiewicz, L'académie en poche, 9/2016

2- Financially support research infrastructure in European universities
3- Develop and increase support for international collaboration programs for researchers
4- Promote STEM (Scientific, Technical, Engineering, Mathematical) studies and careers for the younger generations
5- Campaign for a positive image of responsible research and innovation [37] as a vector of progress for all, in line with the UN objectives for sustainable development
6- Simplification and clarification of the structure of the DG Research and Innovation, avoiding overlaps
7- Upgrading of the EU state aid rules on RDI support in order to provide more incentives for collaboration between SMEs, universities and research centres.
8- Limitation of the scope of the transparency requirement that harms beneficiaries of RDI support since it provides competitors with detailed information on the research undertaken by the beneficiary.
9- Remodelling of the concept that aid threatens to distort competition which is not appropriate for RDI support.
10- Shortening and simplifying the approval process (e.g. limiting the review process for cases raising serious issues to 5 months). The current process: sign grant contracts setting the terms of payment, reimbursement, intellectual property, liability and such is way too long, complex and bureaucratic and a definite deterrent for SME's
11- Transferring the power to approve support for RDI under the EU state aid rules from DG Competition to DG Research & Innovation and generally avoiding potential conflicts between DG Research and Innovation and other DG's (cf. EIT and EIC)
12- A new kind of symbiotic ecosystem according to the rainforest paradigm: shortening social distance, breaking up hierarchies and bureaucracy, promoting easy and quick connections and generalization of successful behaviours: a dynamic, quickly interacting network to seize opportunities, allowing emergence, bifurcation and pivoting.

6- Some pro's and cons

Here, one will notice some improvements and still some difficulties in manoeuvring the huge vessel that is the R&D&I directorate from the Commission.

ATTRACT

Within the Horizon 2020 project, the Commission and CERN came to the conclusion that large BSRI's [38] do develop various designs, devices and others that are used for internal purposes whereas some of them might be utilized in various other fields. In other words, there are possible serendipities that may be spotted, if there are structures to welcome them.

It was then decided to support 170 different projects, with 100,000€ each to work towards a proof of concept application within one year, either by combining different technologies, applying a technology in a field for which it was not conceived in the first place or using AI to enhance a technology: this was the ATTRACT I project, whereas we are already at version II. ATTRACT is a 20 Million € project funded by the Commission and geared towards finding other/new potential for some of the developments of 6 large European Research Infrastructures: i.e. the EIROforum: European Organization for Nuclear Research (CERN), European Molecular Biology Laboratory (EMBL), European Southern Observatory (ESO), European Synchrotron Radiation Facility (ESRF), European X-Ray Free-Electron Laser Facility (European XFEL), and the Institut Laue-Langevin (ILL). The fields of research range from nuclear, particle, and condensed matter physics as well as life sciences,

[37] https://ec.europa.eu/information_society/newsroom/image/document/2016-4/sixth_cop_plenary_meeting_-_presentation_hilary_sutcliffe_matter_13334.pdf
[38] BSRI : Big Science and Research Infrastructures

molecular biology, astronomy, materials science, structural biology and chemistry. ATTRACT 2 is focusing on the most promising projects of phase I, in order to transform the "proof of concept" in industrial applications.

In Science Business news 14/12/2021[39]it was written that « Researchers are now grappling with the new EU (Horizon) research programme, said by its architects to be simplified in its structure, and designed to be much more impact-driven than its predecessors … The reviews are mixed. From praising the lighter administrative touch, to suggestions it would be better to revert to paper submissions, the research community is divided. One thing most agree on is that Horizon Europe calls are more ambitious than ever, and few can fit their proposals into the new 45 pages limit.

After the first round of calls, researchers reported that they struggled to define the impact of their projects, faced uncertainty about associated country participation, there was a lack of clarity about some new features of the application form and they were affected by the delayed launch of the programme while many experienced hiccups on the submissions platform. From an administrative point of view, "They have simplified a couple of things that make it more straightforward," said Cruz Enrique Borges Hernández, researcher at the University of Deusto, Bilbao, Spain. "Now, in the scientific part, it's a hell of a lot harder."

On the question of whether the architects have succeeded in balancing the trade-offs, the jury is still out. **Science|Business will deliver its judgement on Horizon Europe in a report summarising the views of its network members and the broader research and innovation community at its Annual Network Conference in Brussels in February… "It's a complete level harder to build the consortium, to organise the partners, to understand the call and try to put [in place] the right pieces. This has increased the complexity to a huge level,"** said Borges. "You have to do a lot of more things with less budget." Borges is concerned that this new level of complexity in putting big projects together will close the door to the uninitiated. "**The reality is that newcomers won't be welcome, and if they are, only for small tasks. What is going to happen is a concentration of people that have been working on [EU projects] for a long time,"** said Borges.

Marie Latour, secretary general of the European Association of Innovation Consultants (EAIC), said its members had taken time to get used to the new format. With fewer pages and more focus on impact, they reported it was extremely challenging to fit all the needs of the projects into 45 pages. "The amount of information is very similar. So, it becomes very challenging to provide enough information to differentiate from other proposals for very large consortia," said Latour.**As the de adlines approached, many researchers were frustrated with technical issues that plagued the Commission's overloaded platform. Some weren't able to save forms, others were unable to submit proposals or change the participant order**. Taivo Raud, head of the grant office at the University of Tartu, which submitted 98 Horizon Europe proposals in 2021, agreed these shortcomings were a problem. "The main obstacles in the submission process have been technical ones, connected with the funding and tenders portal capability to process all information and data close to the deadline," Raud said.

On February 10, 2022, Science-Business published: "…In its second year as a fully-fledged Horizon Europe programme, EIC will largely continue its work from 2021, but with some change to the funding rules, which for the first time will see it offer start-ups equity backing of above €15 million, support more women-led companies, and increase the budget for top-down calls in health, digital

[39] https://sciencebusiness.net/news/horizon-europe-bigger-and-more-complex-ever-some-cases

and climate to more than €750 million, EIC chief Jean-David Malo told the Science|Business Annual Conference this week."

The Commission's research chief Jean-Eric Paquet confirmed to the Science|Business conference that : "The direction now, is that the EIB[40] would oversee the EIC Fund technically, but the EIB would take up the decisions made by the Commission." The European Parliament and member states are questioning whether this is in line with the original vision of the EIC, which was to invest in high risk start-ups that are unable to attract private investors, and at the same time lower the risk for private investors, attracting them in to later funding rounds. "The Commission granted to take risk and to fund strategically important technologies and – specifically - not to look about the bankability," said **Christian Ehler, Parliament's Horizon Europe co-rapporteur. "I think [the change in management] is a total contradiction to what we as co-legislator envisaged."**

The political dispute about how the EIC equity fund should be managed delayed publication of the 2022 programme and blocked equity funding to companies that won awards in 2021.
The deadlock over the fund management was recently broken, when member states voted to stick to the old rules for now, whilst looking for a suitable fix. The decision to go ahead under the existing rules unlocked the money for 102 companies awarded funding in 2021, with investment decisions expected to be concluded in spring and summer 2022. The same rules will apply to companies that are selected for funding in the first calls this year.

As we can see, structuring and organizing the R&D&I at European level stays a difficult task that creates issues for scaling up European R&D to innovation levels that do exist in other parts of the world.

[40] EIB : European Investment Bank

3. The European Union's Support for Basic Research

by Veronique Dehant and Veronique Halloin

3.1 The ERC objectives

EU research funding brings together a critical mass of public and private resources to make European research and industry more competitive, and at long-term, to benefit to society. It is the way to achieve what no national organization could achieve alone.

Characterized by its bottom-up research-driven and development-driven nature, the ERC (European Research Council) programme is a flagship component of the European Framework Programmes, focusing on basic research at the frontiers of knowledge. It was established in 2007 with the goal of providing funding to investigators to pursue exploratory, ground-breaking, high-risk/high-gain research. It aims to provide Europe's best researchers with the resources they need to allow them to compete more and better at global level.[41]

Researchers at a comparable career stage compete for Starting, Consolidator, Advanced Grants, Proof of Concept or Synergy Grants. All research fields (Life Sciences, Physical Sciences and Engineering, Social Sciences and Humanities) are concerned, and no theme is privileged. Principal investigators (PIs) are free to choose their own research topics and methodologies, and the only criterion for receiving research funding is scientific quality and innovation, which focuses on the excellence of both the project and the principal investigator. This excellence is assessed by high-level international peer review panels. The objective of this direct and very selective competition using peer-reviewing procedure is to identify the best ideas and to support the "best brains" in Europe and also to attract non-European talents. The projects aim at scientific breakthroughs or major advances, in some cases, bridging the gap between pioneering research and early phases of innovation.

The ERC has become one of the world's most important funders of basic research, with high credibility in the scientific community. The overall ERC budget from 2021 to 2027 is 16 billion euros, as part of the Horizon Europe programme, of which it represents 17% of the overall budget. Since its creation, the ERC has funded, with a budget of 20.5 billion euros, just over 10,000 researchers[42]. 891 host institutions in 38 countries are involved.

3.1.1 Metrics of Success for the ERC

Frontier research funded by the ERC is expected to have a significant direct impact in the form of advances at the frontiers of knowledge, ultimately generating radically new ideas that stimulate innovation and address societal challenges. There is no need to justify in terms of metrics such as h-index. Only quality and scientific impact of the research funded do matter. Although not a selection criterion for the ERC, nearly half of the projects have already had an impact on the economy, society, and policymaking, and about two-thirds are expected to have such an impact in the medium to long term. Evaluation study also confirmed the highly interdisciplinary nature of ERC projects[43]. Besides, each ERC grantee employs on average 7 team members, thus contributing to train a new generation of excellent researchers. Currently over 75,000 postdocs, PhD students and other staff working in their research teams.

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[41] https://erc.europa.eu/about-erc/mission
[42] Facts and figures | ERC: European Research Council (europa.eu)
[43] https://erc.europa.eu/news/impact-erc-research-confirmed2020

In addition, the ERC has an important structural impact by stimulating the improvement of the quality of the European research system, beyond the researchers and projects that it funds directly. Indeed, the prestige of hosting ERC grant-holders and the accompanying "label of excellence" intensifies the competition between European universities and other research operators to offer the most attractive conditions to high-level researchers. With the best researchers and ideas competing against each other, applicants know that they must excel to win the challenge. This combination of outstanding individual scientists and innovative ideas underpins every step of the innovation chain.

The ERC grants definitely deserve to be even better funded in the future. The only drawback is the sudden decrease in funding that researchers face at the end of their ERC grant, which is usually not matched by national funding. It must be noted though that the snowball effect of the excellence label acquired by an ERC scientist might help for obtaining funding further.

3.2 Marie Skłodowska-Curie Actions (MSCA)

The Marie Skłodowska-Curie Actions (MSCA) are the European Union’s flagship funding programme for doctoral education and postdoctoral training of researchers. They are also bottom-up kind of financial support for reinforcing European excellence in research and innovation. The main idea of these actions is to equip researchers at all stages of their career with new knowledge and skills, through mobility across borders and exposure to different sectors and disciplines. The MSCA help at investing in the long-term careers of excellent researchers.[44] In these actions, one finds as well support for the development of excellent doctoral and postdoctoral training programs and collaborative research projects worldwide. By doing so, they achieve a structuring impact on higher education institutions, research centers and non-academic organisations.[4] The key words of those actions are excellence, mobility, bottom-up and open to the world. They inforce strategic collaborations, new knowledge, skills and competences as well as future excellent recruitment.
The different programs within the MSCA are the following:

1. Doctoral Networks (DN)[45], which supports programs to train doctoral candidates in academic and non-academic organizations and, beyond to train highly skilled doctoral candidates, stimulate their creativity, enhance their innovation capacities and boost their employability in the long-term.
2. Postdoctoral Fellowships (PF)[46], which supports career perspectives and excellence of postdoctoral researchers. They targets researchers holding a PhD who wish to carry out their research activities abroad, acquire new skills and develop their careers. PFs help researchers gain experience in other countries, disciplines and non-academic sectors.
3. Staff Exchanges (SE)[47], which encourages collaborations between organizations through staff exchanges. The aim is to develop sustainable collaborative projects between different organizations from the academic and non-academic sectors (in particular SMEs), based in Europe and beyond.
4. COFUND[48], which provides funding for regional, national and international programs for training and career development, through co-funding mechanisms.
5. MSCA and Citizens[49], which brings research and researchers closer to the public at large, with a focus notably on families, pupils and students.

The MSCA fellowships are well-known and have served an important part of the scientific community already for brain circulation as well as research and innovation enhancement.

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[44] https://ec.europa.eu/research/mariecurieactions/about-msca
[45] https://ec.europa.eu/research/mariecurieactions/actions/doctoral-networks
[46] https://ec.europa.eu/research/mariecurieactions/actions/postdoctoral-fellowships
[47] https://ec.europa.eu/research/mariecurieactions/actions/staff-exchanges
[48] https://ec.europa.eu/research/mariecurieactions/actions/cofund
[49] https://ec.europa.eu/research/mariecurieactions/actions/msca-citizens

3.3 FET-Flagship Projects

FET (Future Emerging Technologies) is funding frontier research based on radically new visions in order to make major steps towards achieving new creative processes or emerging technologies, turning ideas into innovation. This program focuses on high-risk, long-term, and radical brand new technologies, merging advanced science and cutting-edge engineering[50]. The mission of the FET projects is to tackle the major scientific and technological challenges of our times. They are expected to result in 'game changing' impacts that benefit economy and society and pave the way to the technological and industrial leadership. They are financed by the EU Framework Programmes for Research and Innovation and by the Member States, through a specific partnering model. The FET-Flagships are the most top-down of the three FET programmes. They target ambitious, highly-risky, long term and large-scale research and innovation initiatives. They run typically for a period of 10 years and mobilize hundreds of researchers across Europe with an overall support of around 1 billion euros[51].

Under the FP7 and the H2020 framework programmes, 3 FET Flagships projects have been selected and launched:

- Graphene Flagship (2013), that aims at taking graphene and related two-dimensional materials from academic laboratories to European society.
- Human Brain Project (2013), that aims at a better understanding of the brain, its diseases and its capabilities by providing researchers worldwide with digital tools and platforms for sharing and analysing large brain data sets.
- Quantum Technologies Flagship (2018), that seeks to unlock the full potential of quantum technologies and accelerate their development and take-up into commercial products in Europe.

An interim evaluation of the two first projects started in 2013 was made in 2016, to analyse their capability of delivering their long-term objectives[52]. The evaluation also helped determine the strategic relevance of the FET-Flagships and set the stage for future FET-Flagship programs by helping to refine the current implementation of the two Flagship programs and their governance model. The report indicates that the FET-Flagship instrument is highly relevant as part of Europe's Research and Innovation Strategy and has the potential to have a huge impact. However, there is room for improvement and the report proposes a number of recommendations in that respect.

The FET-Open and FET-Proactive are two FET funding schemes that are part of a newly adopted umbrella funding scheme called the EIC (European Innovation Council) Pathfinder Pilot Programme. They offer grants up to 4 million euros in order to support early stage development of future technologies and allow scientists and researchers to come up with futuristic technologies based on interdisciplinary collaboration[53].

The concept of FET-Flagships (or of the FET-program in general) was mainly supported by the European Commission's DG Connect, while in the meantime DG Research and Innovation has come up with the concept of missions for the new framework program Horizon Europe. Horizon Europe missions do not have exactly the same characteristics as FET-Flagships. In addition, it did not seem

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[50] http://www.fetfx.eu/what-is-fet/
[51] FET Flagships | Shaping Europe’s digital future (europa.eu)
[52] Title (flagera.eu)
[53] https://eic.ec.europa.eu/eic-funding-opportunities/eic-pathfinder_en#ecl-inpage-156

possible to maintain such ambitious instrument, and the FET-Flagship instrument has been abandoned[54].

As part of the Horizon Europe missions, EU is committed to solve some of the greatest challenges facing our world like fighting cancer, adapting to climate change, protecting our oceans, living in greener cities and ensuring soil health and food[55]. The first three Mission Area actions were open for application in June 2021[56] . It is clear that it will take a few more years before the first indicators of success of this new instrument are available.

Research and innovation in Europe certainly need bottom-up funding instruments such as those provided by the ERC and MSCA, as well as more top-down funding schemes such as the FET and the new missions. The challenge is to define the respective budgets to be allocated to the two systems and to identify the right balance to be found.

3.4 CERN

CERN was established in 1954[57] to help to uncover what the universe is made of and how it works. It has become a prime example of long-term international collaboration. While dealing with pure basic research, there are four main goals: discovery through science, technological innovation, bringing nations together, and inspiration and education. In 2014, the Global Science Forum at OECD (Organisation for Economic Co-operation and Development) published a report addressing the potential economic and societal impacts of international research facilities, using case studies of which the largest global research infrastructures was the European Organisation for Nuclear Research (CERN)[58]. Among the beneficiaries of the study were government officials seeking to understand all the ways in which the outcomes of publicly-funded research can benefit national economies and can affect the lives of citizens in general. In this study, four impact categories were analyzed, related to (i) innovations needed for major CERN component development; (ii) innovations unrelated to the facility needs; (iii) software applications; (iv) education and public outreach.

While national research or funding organizations have often developed incentives and mechanisms to facilitate transfer to the commercial sector, the issue is more complicated for international structures. At CERN, a Knowledge Transfer Office (KTO) was established to manage a portfolio of about 40 patents, and this has led to around one hundred license agreements. CERN has also established a network of ten Business Incubation Centers (BICs) throughout its Member States to help entrepreneurs and small businesses to commercialize CERN technologies and expertise. In practice, CERN supports the selected companies through technical visits to CERN, advice and preferential licensing of CERN intellectual property. As mentioned in the OECD report, the case of hadron cancer therapy in CERN should be highlighted, as it represents an innovation development that was not part of the principal scientific objectives, but illustrates how a major research infrastructure can generate impacts beneficial to society without detriment to its main mission.

CERN is thus a perfect example of the importance of a big research infrastructure with many impacts, outside the strict purpose of increasing basic knowledge. Can we therefore identify other big

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[54] Existing flagships will be able to find funding in Horizon Europe because their themes will continue to be funded by Horizon Europe, but it will not be as flagships. Nor will it be via dedicated funding, except for the Quantum Technologies Flagship which is still in its infancy.

[55] Missions in Horizon Europe | European Commission (europa.eu)
[56] Calls for EU Missions now open for submissions (europa.eu)
[57] https://home.cern/about/who-we-are/our-history
[58] CERN-case-studies.pdf (oecd.org)

research infrastructures with a huge potental similar to CERN, which should be created or extended? The needs and opportunities to create such infrastructures should be carefully considered.

4. Powerful European Universities will Create Knowledge <u>and</u> Support Innovation

by Erol Gelenbe

4.1 Introduction

As was indicated earlier in the Executive Summary of this Report, in 2020 the GNP of the United States, the European Union (EU) and China amounted to $20.8bn, $15.3bn and $14.7bn respectively [1], and Europe was almost on a par with the US, ahead of China. But of the twenty largest technology brands in the world in terms of capitalization, only one was European, four of them were Chinese and one was Korean [2]. As for technology companies ranked by revenue, of the top twenty, one was European. Of the top 50 companies by revenue, only 6 were European, and in 2020, European venture capital deals accounted for only 13% , against 50% for the USA, of an estimated $270 billion total across the world [3,4]. These indicators from 2020, which (at the time) included the UK within the EU, tell us that despite its history and culture, the size of its population and the quality of life that it offers, the EU has not yet reached the level of economic investment for the future that one would expect from its material wealth and rich cultural, technological and scientific heritage. Yet Europe has long benefited from large research organizations (CNRS, Max-Planck Gesellschaft, EMBO in fundamental biology, CNR and INFN in Italy, CERN, INRIA, etc.) and research and technology organizations (RTOs) such as Fraunhofer, CEA, VTT in Finland, IMEC in Belgium, etc. Moreover, in 2020 Europe alone with 7% of the world's population still produced 21% of the world's scientific publications, ahead of the United States and matching China (21%) [5]. On the other hand, the majority of Nobel Prizes have been awarded for many years to researchers who earned their PhDs in the United States (even for a few recent "young European" Nobel laureates), a country whose universities also recruit Nobel laureates from other countries in the fields of literature and science.

Similarly, European industry also invests less in research than its counterparts in the US and China (but more than its counterparts in Japan). Indeed, recent technology-based industrial and economic developments, first in the United States and then in Asia, have been supported by major investments in these countries' science, technology research and in higher education, while Europe has made efforts through the Framework programs, and in innovation, but the EU countries' investments in technological research over the past three decades have still lagged, despite many positive initiatives to support industry-university cooperation [6].

4.1.1 Some Recent Successes of European Universities

The EU's scientific and technological fabric has indeed benefited from the research programs of the European Union, while recent efforts to stimulate innovation of industrial or academic origin via the EIT (European Institute of Technology) or the new EIC (European Innovation Council) have not yet fully provided the advances that are hoped for. Indeed, the sums committed are sometimes insufficient, the bridges towards innovation at higher Technology Readiness Level are not well constructed, some of the administrative constraints are excessive, and there is still a significant backlog in base funding for the higher education and research fabric in most of Europe as compared to our major competitors [7].

Despite these difficulties, a recent report on the Horizon 2020 and FP7 programs [8] acknowledges the success of universities and SMEs in European innovation, stating that "Furthermore, 70% of high potential innovations are co-developed by universities; collaboration between universities and SMEs appears to be particularly successful, and new products are co-developed much more often in collaboration involving universities ...". This is similar to the situation in the United States, where the knowledge and know-how disseminated by universities result in "start-ups" that are often created by academics or recent doctoral graduates, and are the source of a significant portion of the innovations that resulted in the steady increase in that country's wealth in recent decades.

Indeed, the critical value of universities collaborating with both start-ups and large companies was again dramatically demonstrated by the development of Covid19 vaccines in record time. Two of the Covid19 vaccines developed and commercialized by outstanding R&D programs in Europe are the result of the work of university teams, including Biontech in Germany by Turkish-born professor Uğur Şahin of the University of Mainz, Dr Özlem Türeci and their team, and the Astra-Zeneca vaccine by Professor Sarah Catherine Gilbert of Oxford University in the UK. Moreover, the Moderna vaccine in the United States, just as the Biontech vaccine, is based on earlier pioneering work of the Hungarian-born Professor Katalin Karikó, who worked in the USA for several decades with Professor Drew Weissman at the University of Pennsylvania.

So, we see once again in this pandemic that Universities can offer unexpected solutions to some of our main challenges, just as in the 1980s it was Universities that launched the great "catching up" of countries such as Belgium, Germany, the UK or France in the field of informatics, a scientific and engineering subject and an industry that was underestimated at the time in Europe, but is now widely recognized as being absolutely crucial.

4.1.2 Comparing Germany with the USA and the UK

According to the Goethe Institut, even Germany underspends on education in general and universities in particular [9], stating that "Expenditure on higher education has increased overall in Germany; nonetheless, per student spending is still below the OECD average. Germany spends around $9,000 per student, while the average figure in OECD countries is $10,200. By way of comparison, the United Kingdom spends almost $16,000 per student, and the USA as much as $21,000. Germany has fallen behind in this area because the number of students has grown faster than expenditure. One thing is special about Germany: most higher education costs there are covered by the state, the finance ministry stumping up 86% of the total. 57% of the tuition costs in the United Kingdom are paid by the state, while the figure is a mere 32% in the USA. In other words, students there have to shoulder a much greater share of their university expenses." These sums represent base funding and do not include income from research in Germany, the UK or the USA.

4.1.2.1 Publicly Funded Academic Research Budgets in the USA

Since Germany is both the most populous and largest economy in the EU, it is tempting to compare it with our -- arguably -- largest competitor, the United States. If we examine the public research budgets received by Universities, we would see that the USA NSF budget for Fiscal Year 2021, which represents only 25% of the Federally funded research carried out by USA universities, was $8.45 bn [10], so that Federally funded university research budgets in USA Universities totaled $33.9bn that year. On top of that, the USA Department of Energy Laboratories, contributed roughly $35 bn more to US Federal research expenditures in 2020 [11]. We are not including the substantial research budgets from more applied DoD agencies, nor those from the Department of Commerce (such as NIST with an over $1bn), or the SBIR funding (roughly $3.2bn), or STTR (roughly $450m) i the most recent years. The university funding from NASA, DARPA/ARPA and NIH would be largely included in the $33.9bn Federal research funds spent annually by universities.

These sums can be compared for Germany with the €3.77 bn annual publicly funded budget of the Helmholtz Association [12], €0.9 bn annual public funding of Fraunhofer (roughly 30% of its income) [13], and the €1,92 bn budget of the Max Planck Society [14]. These sums total to roughly €6.6 bn or $7.25 bn (at the current rate of exchange of $1.1 per euro).

It is also interesting to compare this on a per capita basis, with the USA population being nearly four times larger than the population of Germany. Just taking the Federal funding of university research in the USA plus (just) the Dept. of Energy national laboratories for a total of $68.9 bn, dividing by four we have $17.2 bn (not counting other US Defense R&D), to be compared with the $7.25 bn received annually by Germany's publicly funded reseach organizations: we observe an astounding 230% (17.2/7.25) superiority for the USA with regard to Europe's economically most powerful nation. This illustrates the chasm we have to understand and face.

This comparison needs to completed by the total amounts (averaged per year over seven years 2014-2020) obtained from the Horizon programs by Germany and the UK, even though most of these sums are not received by universities or Research and Technology Organizations (RTOs) alone, with industry being often the larger beneficiary. Indeed, it appears that [16]: "The United Kingdom received 12.1% (€7.26 bn) of the Horizon 2020 funding over 2014-2020; by comparison, the country's average contribution to the overall EU budget is around 11.4% of the total. Germany took home the biggest percentage of Horizon 2020 funding (€8.94 bn or 14.9%), but it contributes a higher percentage to the overall EU budget (20.9%). Likewise, France's funding share (€ 6.6 bn or 11.1%) was lower than its average contribution percentage to the EU budget (17%; see 'Gains and losses')."

Correcting with the total amounts obtained from the Horizon programs by Germany, even though most of these sums are not received by universities or Research and Technology Organizations (RTOs) alone, with industry being often the larger beneficiary, we add the German income from Horizon 2020 (averaged for seven years at €1.27 bn per year for Germany) to the previous calculations. The superiority of the USA funding as compared to Germany becomes "only" 198% (17.2/8.65).

4.1.2.2 Comparison with the UK

The main public research funding for the UK is UKRI which, for the Fiscal Year 2020/2021, had an overall government allocated public budget of £7.908 bn (or $10.43 bn). As stated on the UKRI web site [15]: "This provides an increase in excess of inflation to the core research and innovation budgets of UKRI councils and enables us to continue planned activity in our Strategic Programmes (formerly National Productivity Investment Fund). UKRI's budget is 10% higher than in our first year of operation in 2018-19. Total UK public investment in R&D has also increased over this period, rising from £13.2 billion in 2020-21 to £14.9 billion in 2021-22, an increase of 13%."*Thus the public research funds which are largely allocated to Universities on a competitive basis in the UK, exceed by 43% the total amount of Helmholtz, Fraunhofer and Max-Planck Associations' public funds.*

If we include the UK and German incomes from Horizon 2020 (averaged for seven years at €1.03 bn/year for the UK and €1.27 bn for Germany) in the previous calculations and compare all the results in USD at 1.1 USD to one Euro, and 1.32 GBP to one USD, the public research funding from public sources (most of which goes to Universities) shows a 35% advantage of the UK as compared to Germany. This would rise to roughly 40% if we correct for the relative population sizes.

On the other hand, taking the UK population to be 68 million and hence with a 1:4.85 ratio with respect to the US, we obtain an equivalent of the public monies supporting university related research of $14.2 bn for the USA, resulting in a quantitative superiority of 136% in favor of the USA with respect to the UK in view of the relative size of their populations.

4.2 The Funding Model of Universities in the USA

Funding of universities in the USA is based on tuition fees, publicly funded budget allocations in the public universities, research grants from public research agencies for both private and public universities (which have been also discussed in Section 1), tax deductible industry gifts and contracts, and private endowment, the latter totaling more than $837 bn nationwide in 2021 for 734 institions of higher education [17], which is a large capital investment than the €500bn that the EU has committed to combatting *all of the economic consequences* of the Covid-19 pandemic.

In addition to private universities, the $837 bn endowment in the USA includes many public institutions. Examples include the Universities of Texas System, such as UT Austin, UT San Antonio, UT Dallas, the Houston Medical Center, UT El Paso, etc., which totals $31 billion, the University of Michigan's (Ann Arbor) endowment of $11.9bn., or the over $4.4 billion endowment of Michigan State University (East Lansing).

Note that the level of spending from the university Endowments Funds, which are invested primarily in publicly traded companies, averages 5% of the value of the funds. So we're talking about an annual national expenditure of endowment income of about $40 billion in total. Referring just to the University of Texas system that has some 240,000 students and over 100,000 faculty and staff in 14 institutions with total income of $21 billion (2020 figures), the additional $1.5 billion per year from its endowment offers a significant amount for investments in these institutions. Other examples of endowments include $8.52 billion for Washington St. Louis University, which at a 5% spending rate provides $426 million per year in coverage of the university's operating expenses, Harvard's $38 billion which covers 35% of its operating expenses, Princeton's $26 billion or MIT's $16.5 billion, or Yale's $29 billion, which is then able to spend more than $1.5 billion a year on teaching and research, not counting revenue from tuition and research contracts.

Overall, 49% of the university endowment in the United States is used to provide scholarships or financial aid to promising as well as needful students. A substantial fraction is devoted to attracting and supporting "endowed chairs" for senior academics who are themselves able to attract substantial research income to support their PhD students, laboratory expenses, research teams and junior researchers. Thus, the endowments of U.S. universities are amply supplemented by competitive grants and research contracts (as discussed in Section 1) from the federal government (DoD, NSF, NIH, NASA, etc.) that typically include 45% or more of overhead in addition to direct expenses, and by donations from industry and individuals.

An interesting and atypical, but not unusual, example is the Olin College of Engineering in Massachusetts, which has 350 students and a capital endowment of more than $1 million per student, allowing it to provide high-quality education-including through research-in a very small institution. According to its own website, its faculty mission statement states that: "An important facet of the role of an Olin faculty member is to engage in meaningful outward-looking work through activities such as research, entrepreneurship, technical and educational advising, and creative work ... Indeed, this research accomplishes much more than just training the scientists of tomorrow; it also has an impact today" [18]. Another relevant example is the Cooper Union in New York City with high quality undergraduate programs in Architecture and Engineering, and an illustrious list of graduates who have won most of the highly recognized awards in science, engineering and architecture [19].

Thus, what we describe is not limited either to very wealthy historical universities such as the Ivy Leagues, or exceptional private or public institutions such as Stanford, Duke, MIT, University of

Michigan, University of Illinois, University of California Berkeley, or the University of Chicago, nor to very well endowed public institutions such as the University of Texas System. Very recently, the third ranked public university in the state of Michigan, Western Michigan University in Kalamazoo, announced a new $550 million endowment [20] raised through the efforts of its alumni, showing us once again that the "most capitalist nation" places the highest value in both public and private higher education, and reminds us of the challenges that we Europeans face in this respect.

The continued vitality of American universities, and the "Biden Impetus" [21], are also well illustrated by the one year increase in the number of foreign students who decided to study in the USA in the Fall of 2021 after the significant drop in numbers during the Trump years [23], announced by the Institute for International Education (IIE) [22]: "The findings from the Fall 2021 Snapshot reflect the resilience of the U.S. higher education system in the COVID-19 pandemic and its continued support for international students. With large increases in new international student enrollments, the findings point to a potential rebound of international student totals in the 2021/22 academic year, with further recovery in future years."

4.3 The Need to Improve the Base and Research Funding of European Universities

We believe that there is an urgent need to improve the base funding of European universities and reduce individual teaching loads, administration and bureaucracy. High teaching loads, preparing lectures, contact hours with students, administrative workload, budget management and administrative constraints, significantly limit the creative capacity of academic staff and their capacity to collaborate with the industrial and productive sector, which is at the heart of our concerns. EU universities should not be pressured to admit students who do not have the background needed to commence university studies. Admissions of students from outside the EU should focus on postgraduate studies and research, rather than on undergraduates.

Student-academic staff ratios in tertiary education, 2018
(number of students per member of academic staff)

	Tertiary total	Short-cycle tertiary	Other tertiary
EU-27 (*)(*)	15.3	:	:
Belgium	21.0	:	:
Bulgaria (*)	11.5	–	11.5
Czechia	15.0	11.4	15.0
Denmark	15.6	18.6	15.3
Germany	12.0	12.2	12.0
Estonia	12.8	–	12.8
Ireland	:	:	:
Greece (*)	38.7	–	38.7
Spain	12.3	10.9	12.7
France (*)(*)	16.2	12.3	17.4
Croatia	12.5	:	12.8
Italy	20.3	–	20.3
Cyprus	22.0	15.5	23.2
Latvia	16.3	13.2	18.1
Lithuania	14.4	–	14.4
Luxembourg	4.4	8.7	4.0
Hungary (*)	11.5	12.8	13.7
Malta	9.4	7.9	9.6
Netherlands	14.6	12.5	14.7
Austria	13.8	8.0	15.8
Poland	13.8	9.8	13.8
Portugal (*)	14.3	:	:
Romania	19.8	–	19.8
Slovenia	14.4	22.2	13.7
Slovakia	11.4	7.2	11.6
Finland	15.3	–	15.3
Sweden	10.1	7.2	10.2
United Kingdom	15.4	:	:
Liechtenstein	11.9	–	11.9
Norway	9.4	11.4	9.3
North Macedonia	17.3	–	17.3
Serbia (*)	24.2	–	24.2
Turkey	26.1	66.8	20.6

(*) 2017.
(*) Excluding Ireland; coverage deviations noted for Bulgaria, France and Portugal also apply.
(*) Excluding doctoral or equivalent students enrolled in scientific organisations.
(*) Excluding private institutions.
(*) Short-cycle tertiary education and other tertiary education: 2016.
(*) Total tertiary education and other tertiary education: includes post-secondary non-tertiary personnel giving courses in higher education institutions.
(:) not available
(–) not applicable
Source: Eurostat (online data code: educ_uoe_perp04)

eurostat

As an example, in the early 1980s, when the top American universities (notably the 250 or so universities in the USA R1+R2 rankings) were reducing their individual faculty teaching loads from 60 to 120 contact hours per academic year, with typically small classes of 25 to 50, and improving salaries to be able to attract more faculty in engineering and professional disciplines, university professors and lecturers in France were uniformly "gratified" with a massive increase in teaching hours from 75 hours to 192 hours per year, often in front of groups of 200 or more students.

This being the case, one might ask whether the situation is very different in the great international universities that we admire so much for their contributions to the scientific and economic development of their countries and the world as a whole. To do so, let us first the widely varying average number of students per academic staff member in universities in Europe as shown in the Eurostat table given above (for 2018). Indeed, if one looks at the situation of the "top 100" universities in the Shanghai ranking, or even the "top institutions" in most other rankings, the ratio of the number of students per (full-time) lecturer or professor of any rank gives a glimpse of the teaching load of academics, and the resulting limits that are imposed on their creative activities and their ability to contribute to research and innovation.

Data for the ten top UK universities show a typical teaching staff to student ration around 10 [24], far from the average ratios in most EU 27 countries and the UK that are reported summarized in the table in this Section. If we consider other universities in the "100 best" of the Shanghai list, we see that in the United States, Duke University has a ratio of 3.92:1, Washington St. Louis University a ratio of 4.26:1. Under these conditions, can we expect the same scientific productivity, or the same concern for applied research jointly with industry, or for winning research grants and contracts, from an academic staff member in a university with 18-21 students per academic staff, as compared to another university with resources that allow it to recruit twice as many academic staff for the same number of students?

And what about the number of doctoral students that these academic staff can supervise? Indeed, various evaluations of universities in the United States find that the science and engineering departments at top research universities may average two PhD graduations per year per faculty member, which would mean -- over an average four-year doctoral period -- that they each supervise on average at least eight doctoral students. We say "at least" because various factors, such as the inevitable interruptions of some students' doctoral studies, and the attraction of jobs in industry, naturally reduce the efficiency or productivity of doctoral training. Eight doctoral students to one professor is double of what is accepted as an upper limit in most universities in France, where teaching loads and administrative constraints are applied uniformly, seldom taking into account research leadership, creativity, fundraising ability and the faculty members' ability to develop industry collaborations or new research topics and areas.

4.4 Some Thoughts about UK Universities

Oxford and Cambridge are an exception in Europe and in the UK with their substantial endowments from the Colleges' constituent foundations as well as from the universities' own endowments. Indeed, in 2019, Oxford University was reported to have a combined endowment of £6.1bn, while Cambridge was reported to have an endowment attaining £7.1bn. This allows them to spend several hundred million pounds of discretionary funds each year to support their students, staff and infrastructure. Well behind, the University of Edinburgh enjoys an endowment of £565 m in 2021 [25]. This financial capacity has enabled the them to attract renowned academics and high-level doctoral students, who in turn attract greater income from research grants and contracts. In the year ending July 31, 2018 [27]: "The greatest single source of income to the university was through research grants and contracts, having gained £525 million .. " or around 27% of its total annual income. This contrasts with the total of €435m (12% of its annual budget) in research contracts and grants (to which one may add circa €46m in royalties, service fees and gifts) attracted by CNRS in 2018, the major French institution with a total budget of €3.7bn euros that focuses on research and to a far lesser extent on technology transfer [28].

However, most UK universities (except for Scottish Universities where Scottish students do not themselves pay tuition fees) receive a majority of their income through substantial tuition fees, in the range of roughly £9,000, per year for students who are UK citizens or permanent residents, and £15,000 to £25,000 or more per year for non-UK resident students. To finance these fees, many students contract loans, and the so far unpaid loans total £141 billion up to March 2021. The average debt incurred by students in the UK varies widely based on regions, going from about £15,000 for students in Scotland to as high as £45,000 for those in England. This may eventually lead to huge debt of some £560 billion (2019-20 prices) by 2050 for English students alone, which will be difficult to finance and sustain [29,37].

In 2014/2015 UK universities received £5.9bn in research grants including £826m through EU programs, while the UKRI budget for academic research rose to £7.908 bn (or $10.43 bn) in Fiscal Year 2020/2021 [15]. UK Universities and industry have received on average 1 bn per year from the EU for research as a consequence of their strong technological and financial base between 2014-2020 [16], and the UK government has also recently announced a new £800m annual multidisciplinary "disruptive" research program (ARPA) [32] for highly innovative research that should compensate the sums lost by UK research after Brexit . Since the UK has now left the ERASMUS programs, its universities will no longer bear the costs of non-tuition paying European students, and the recent agreement between the University of Manchester with the Universities of

Melbourne in Australia and Toronto in Canada illustrates the shift of the UK's attention regarding academic programs towards its traditional links to the Commonwealth and the English speaking world [34]. Thus the UK's largest universities will be able to secure their needed tuition income after Brexit, while their new EU students (surely fewer in numbers as compared to the previous period) will pay the same fees as other non-UK students starting from 2021.

4.5 Recent Successes in France

It is only fair to salute the success of policies carried out since the 2010s by three successive Presidents of France. Indeed, after efforts to restructure French universities over the last decade, today France has five universities that are among the top 100 in the Shanghai ranking, up from just two previously. The mechanism that was instituted to drive these changes is the "Investissements d'Avenir" program [30] that is funded as a form of endowment not just for universities but also in support of major technological transitions, and has allocated large grants to universities based on competitive project submissions via the ANR agency [31]. The purpose of these grants is not just to support major facilities and infrastructures, but also to make major changes in the academic structures themselves, both in the organization of teaching and research.

Some of the resulting successes of this progam include the University of Paris-Saclay (now in the top 15 world-wide), while Paris Sciences-Lettres and Sorbonne University are now in the top 50, while the University of Paris and Grenoble Alpes University are in positions 65 and 99 of the Shanghai rankings. Aix-Marseille and Strasbourg are next in the 101-150 range. These improvements in world rankings are important because these universities will be able to attract more top undergraduate and doctoral students, excellent professors, especially from abroad, and more EU grants and private funds.

These successes also underline the failures of policies pursued in the 1970s to the 1990s, with excessive specialization and "atomization" of university centers. They demonstrate the importance of having universities with a varied and non-homogeneous structure, to ensure a balance between selective and less selective teaching programs, between teaching and research, and the ability to include teaching departments and research laboratories funded by both public bodies and industry. These restructured universities include "colleges" derived from the Grandes Ecoles as well as three year Technology Institutes (IUT), and jointly funded private-public laboratories, as is the case at Paris-Saclay, and other institutions such as Ecole Polytechnique.

4.6 Defense Research

Although the European defense industry is among the most technologically advanced in the world and accounts for about 20% of the global defense revenue, Europe lags in the global share of equipment exports and the R&D in member states often duplicate each other. According to the European Commission, the newly created European Defense Fund (EDF) [35] has a budget which is only 13.5% of the entire public defense R&D budget in the US. Despite more ambitious objectives, the proposal was trimmed for the period beyond 2022 to only €7.9 billion, but the European Commission and member states hope that it will leverage funds from industry partners and member states of up to €40 billion in investments with positive impact for both military and civilian applications, and help justify a higher budget in the next budgetary cycle. In its first year, the EDF will co-finance projects worth €1.2 billion, thanks to a top-up of €290 million from the 2022 budget. The Commission says the boost will kick-start large-scale projects for developing the EU’s defense capability.

EDF is the first EU program to finance common defense-related R&D projects. It builds on previous work by the preparatory action on Defense Research program launched in 2017 with a budget of €90 million for two years, which was followed by the European Defense Industry Development program (EDIDP) with a budget of €500 million for 2019-20. According to Thierry Breton (EU Commissioner for the Internal Market) "In 2021 alone, the EDF will finance up to EUR €1.2billion in high-end defense capability projects such as the next generation of aircraft fighters, tanks or ships, as well as critical defense technologies such as the military cloud, AI, semiconductors, space, cyber or medical counter measures". The Commission recently announced 26 winning projects worth €158 million out of a call for applications organized under the umbrella the EDF's precursor fund.

EDF is part of a broader strategy by the EU to flex its geopolitical influence and the need of EU member states to increase their defense budgets to 2% of their GDP. According to Thierry Breton "Without putting into question historic alliances, Europe can no longer be constrained by choices and decisions made by others, ... With the European Defense Fund, Europe is definitely taking its destiny in its own hands." The program will finance the development of high-risk, disruptive technologies, in Europe's attempt to become a major player in a domain that can also have a big impact on the civilian economy. Of the total budget, 8% will be allocated to the development of disruptive technologies with both military and civilian applications. "These disruptive technologies and innovative equipment will be extremely important for our competitivity in the coming years and decades," according to Romanian MEP Buşoi, Chair of the European Parliament's research and industry committee.

The greater integration of European Universities in these efforts, and in particular on high-risk disruptive technologies, would involve more post-graduate students and academics in new challenging yet focused research initiatives, and in understanding and formulating the EU's security needs and agenda.

4.7 Conclusions

As we complete this tour of some salient aspects and comparisons that concern the capabilities of European universities, we need to look to the future with the ambition to "turn them on" to become the driving forces for technology and innovation in Europe. The world relies critically on knowledge generated by universities, and we cannot leave our universities behind. Better links between universities, industry and business can improve our health, well-being and security, our ability to help our world neighbors, and our capability to provide for future generations [30].

Investments in higher education and research in China, Singapore, Korea and the United States are leading the trend to strengthen universities and achieve technological breakthroughs. Thus, the US Department of Education recently released $21bn for US universities, while the US President proposed an additional $35bn for higher education, and a $250bn research funding plan for the next several years.

Europe must remain a leading player in this highly competitive arena, and attract the best scholars, researchers and educators to our universities. We need to step up to these challenges in the old Europe that so many of us love to work, study and live in, to provide viable employment for our youngsters, creating the means for Europe to maintain a leading role. We need to make science and technology and its valuable outcomes, available openly to all [38,41], and understand and tackle obscurantism and science disinformation [39].

To reach these aims, let us firmly and generously support our educators, scientists, our scholars and together with their efforts, but let us especially support our youth, giving universities the capacity to attract the best and brightest to our continent, and the opportunity to develop the knowledge to address the challenges of climate change, global health, security, inclusiveness and diversity.

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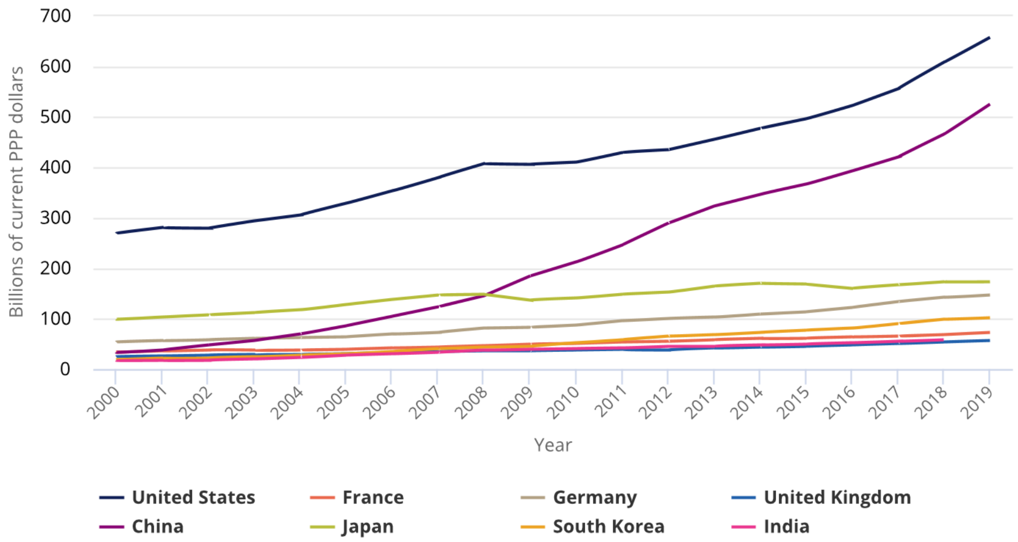
5. Current trends in the US and in China

Prepared by Guy Brasseur

5.1 Some statistics

The innovative capacity of a nation is determined, among many other indicators, by the level of its investments in research and development (R&D). Worldwide R&D investments have tripled from 2000 to 2019 with global values having increased from $726 billion in 2000 to an estimated $2.4 trillion in 2019. At present, the largest contributions to R&D expenditures are provided by the United States (27% or $656 billion) and China (22% or 526 billion). Contributions from other countries are substantially smaller (7% for Japan, 6% for Germany, 4% for South Korea and 2-3% for France and the United Kingdom). What is striking in the Figure 1 is the substantial increase as a function of time in the case of the US and China. Little change over time is noticed, for example, in the case of European nations. What is obvious in Figure 2 is the rapid increase in the relative share of R&D in the case of China (4% in 2010 and 22% in 2019). In relative terms, this share has decreased in the case of the US (37% in 2010, 27% in 2019) and of the European Union (22% in 2010, 18% in 2019).

Gross domestic expenditures on R&D, by selected country: 2000–19



Note(s):
PPP is purchasing power parity. Data are for the top eight R&D-performing countries. Data are not available for all countries for all years. Gross domestic expenditures on R&D were revised from those reported in previous years of *Science and Engineering Indicators*. These data revisions were mostly due to 2020 revisions of the PPP estimates. See sidebar Revisions to Global Research and Development for more details.

Source(s):
NCSES, National Patterns of R&D Resources; OECD, MSTI March 2021 release; UNESCO, UIS, R&D dataset.

Indicators 2022: R&D

Figure 1

Shares of worldwide R&D expenditures, by selected region, country, or economy: 2000, 2010, and 2019

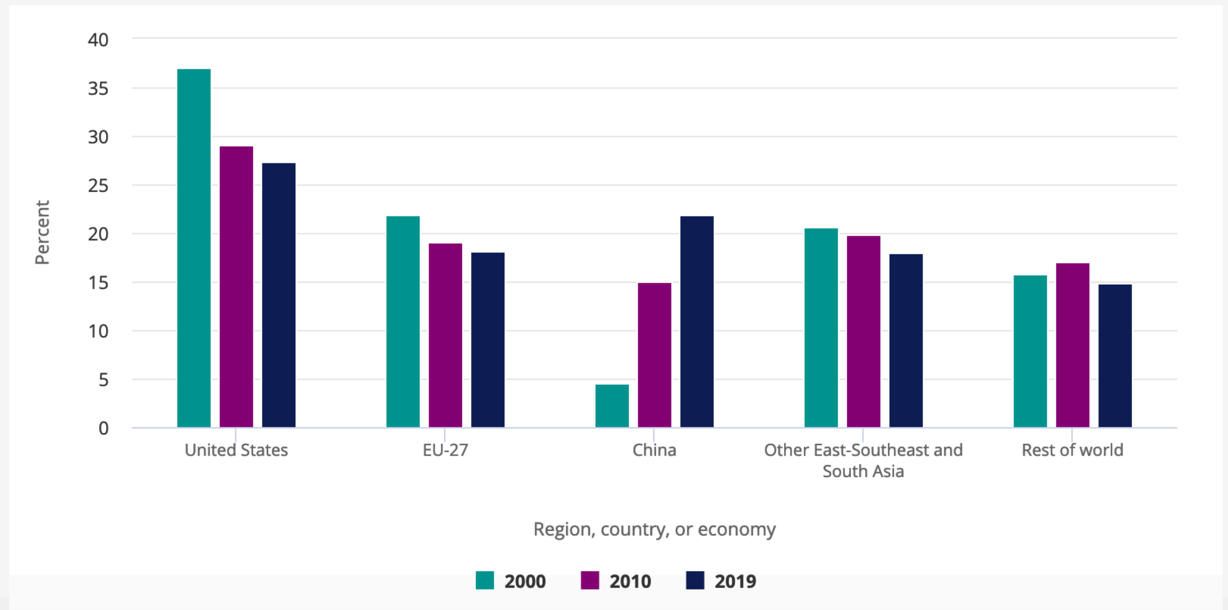


Figure 2

The productivity of a nation in terms of its research and development can also be represented by the number of publications in the peer-reviewed literature and a second one is the number of international patents. During the period 2010-2019, the index for highly cited publications (Figure 3) has remained relatively unchanged in the United States, but it has increased considerably in China and to a lesser extent in Europe, India and Japan. In the case of international patents (Figure 4), the share between 2010 and 2020 has increased from 16% to 49% in China, but has decreased from 15%

to 10% in the US and 12% to 8% in the European Union. Today, about half of the international patents in the world originate in China.

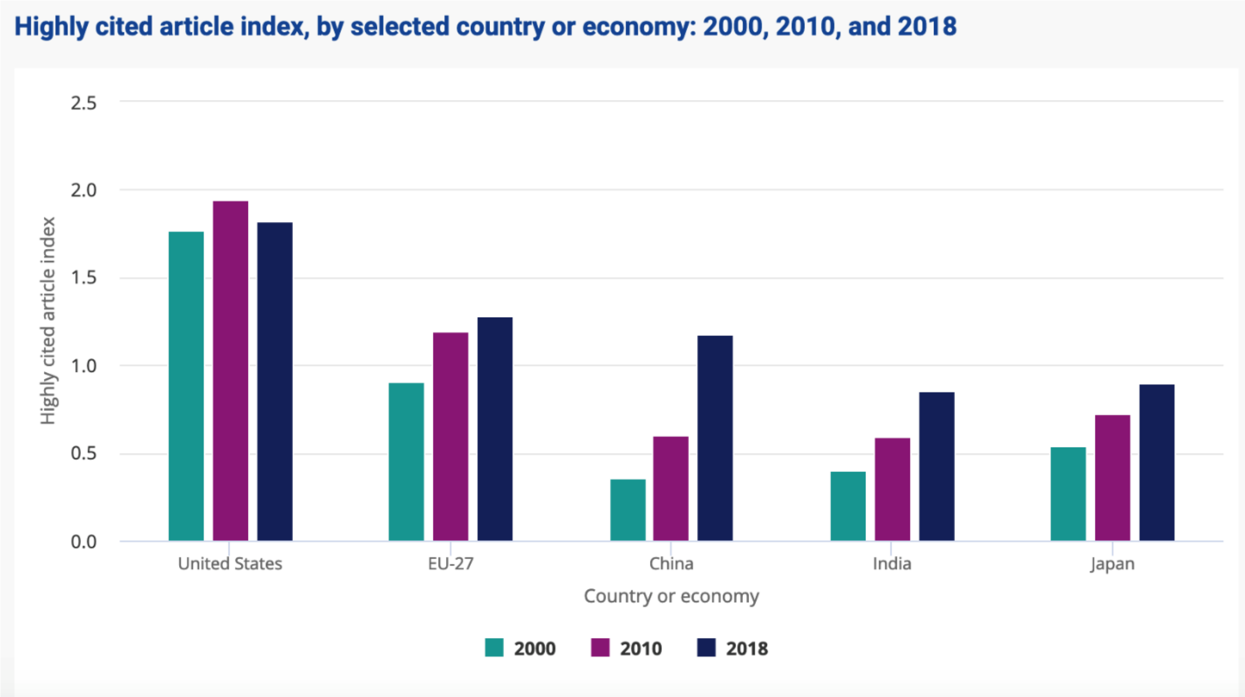


Figure 3

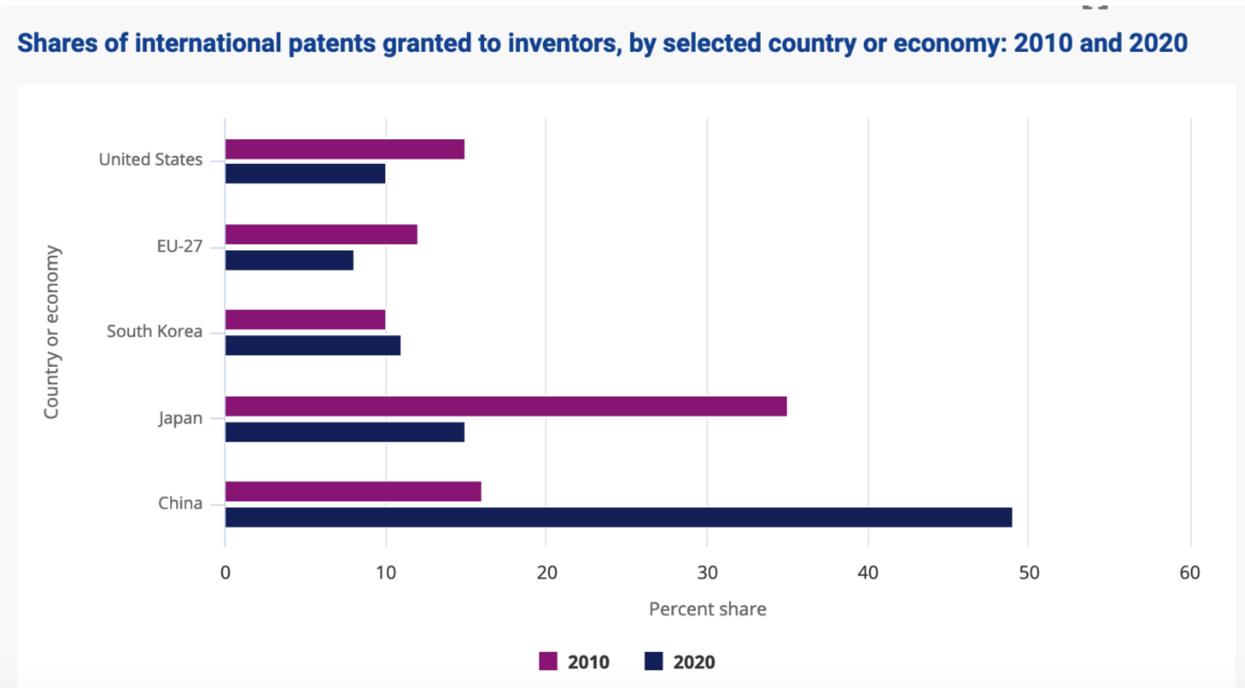


Figure 4

These figures suggest that Europe is facing a major geopolitical challenge: the development of an accelerated process of innovation supported by an intense effort of scientific and technological research. Europe is, in fact, in direct competition with the aspirations of other continents including

Asia, in particular China, and North America, in particular the United States, in their hope of dominating the world's global economy and of providing to their inhabitants the benefits of a high domestic product. Europe, if it wants to keep its influence as a geopolitical power, must give itself the means for its development while promoting its humanist model based on democratic values and social justice.

5.2 China

China has understood what is at stake. It knows that its accession to the title of world power requires the implementation of an ambitious program of scientific and technological research. The fourth five-year plan (2021-2025) and the country's long-term objectives (until 2035) attempt to boost technological innovation, ensure the country's self-sufficiency, increase domestic demand and maintain national security. Key objectives of the Chinese plans are the following:

1. Increase the urbanization rate of the resident population to 65%.
2. Average annual growth of over 7% in social investment in R&D.
3. Cut energy consumption and carbon dioxide emissions per unit of GDP by 13.5% and 18% respectively and increase forest coverage rate from 23.04% to 24.1%.
4. Keep urban survey unemployment rate within 5.5%.
5. Synchronize growth of per capita disposable income with GDP growth.
6. Increase average years of education of the working-age population to 11.3 years.
7. Increase participation rate of basic pension insurance to 95%.
8. Increase life expectancy per capita by 1 year.
9. Increase percentage of the digital economy core industry added value on GDP to 10%.

Key priorities for science and technology are:

1. <u>Next Generation Artificial Intelligence</u>: R&D of special chips, construction of open-source algorithm platforms, innovation in natural language recognition processing.
2. <u>Quantum Information</u>: Research and development of intra-city, intercity and free-space quantum communication technologies.
3. <u>Integrated Circuits</u>: R&D of key materials, breakthroughs in advanced and special integrated circuit processes, development of broadband semiconductors.
4. <u>Brain Science and Brain-like Research</u>: Brain major disease mechanism and intervention research, child and adolescent brain intelligence development.
5. <u>Genes and Biotechnology</u>: Genetic cell and genetic breeding, synthetic biology and biopharmaceuticals, creation of major new varieties of crops, livestock, aquatic animals and agricultural microorganisms such as innovative vaccines.
6. <u>Clinical Medicine and Health</u>: Basic research on the pathogenesis, prevention and treatment of major transmissible diseases and major chronic non-transmissible diseases.
7. <u>Deep Space, Deep Earth, Deep Sea and Polar Exploration</u>: Interstellar exploration, space transportation systems.

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5.3 The United States

Since the end of World War II, the United States of America has played a significant role in scientific and technological advancements. This role became essential during the space race, which had considerable economic benefits for society. The research was carried out collectively by universities, national laboratories, private industry and the military sector. Federal government funding of research hit a peak in 2010, but for more than a decade, especially under the Trump administration, but already during the Clinton and Obama periods, the increase in the research effort has weakened somewhat, perhaps because the geostrategic stakes had become less convincing. The level of funding today has not gotten back to the 2010 level. The fraction of the research and development supported by defense programs has often been higher than the fraction attributed to non-defense needs (see Figure 5).

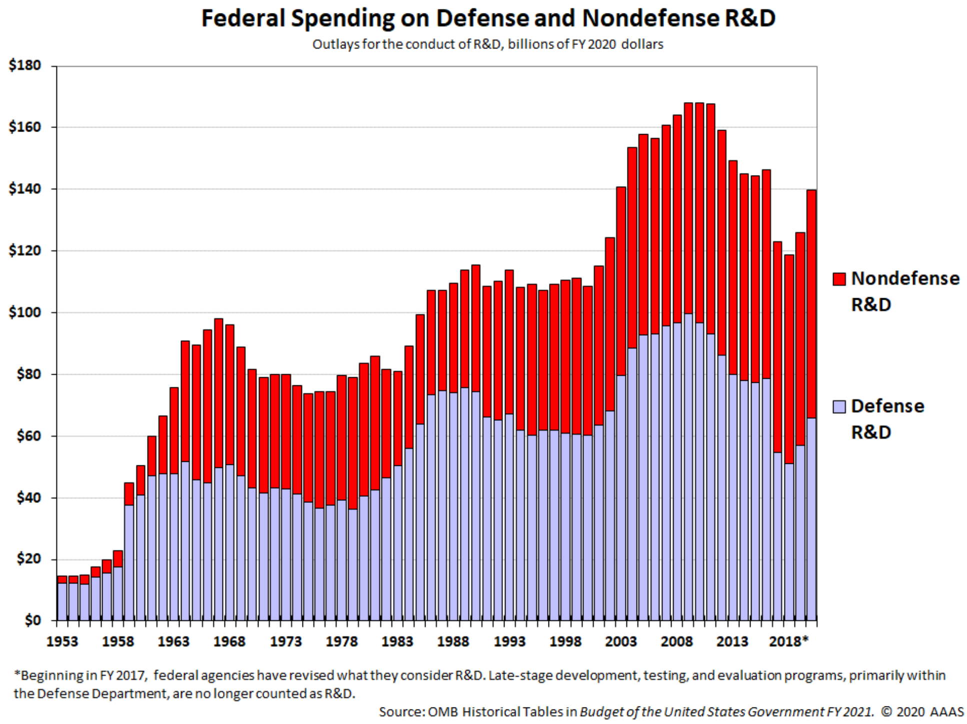

Figure 5

When considering the non-defense part of the R&D programs (Figure 6), it is immediately noticeable that most investments have been directed towards the health sector. The fraction related to space research, very high in the 1960's, has decreased in the following years with a modest but steady-state situation starting in the 1990's. The research in energy was strongly supported after the oil crisis of 1973, but is now considerably smaller. Support for general science has gradually increased.

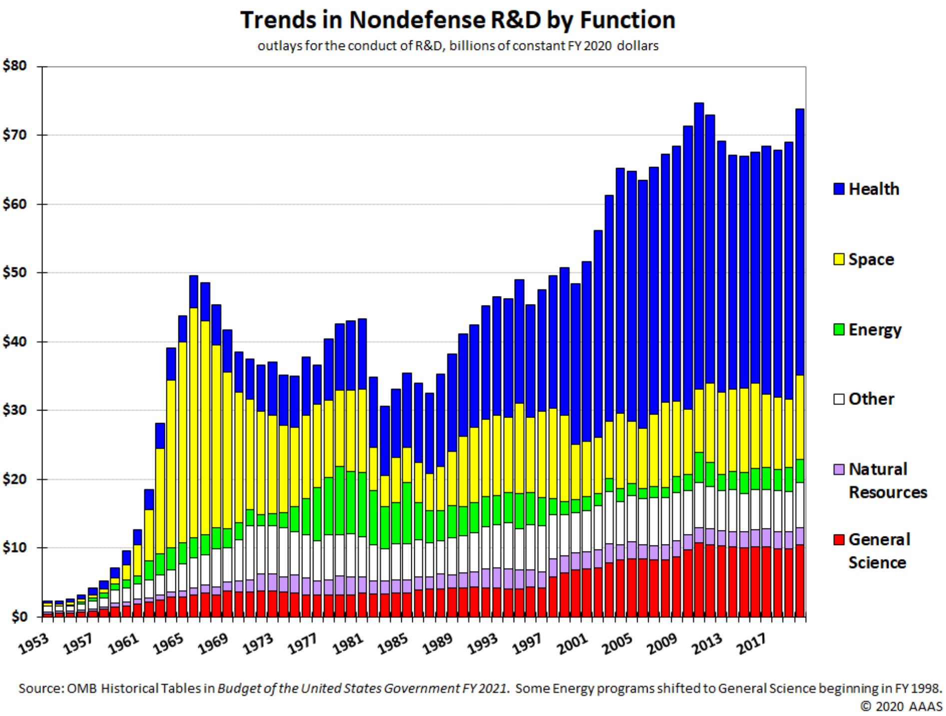

Figure 6

In recent decades, universities have been increasingly encouraged to engage in interdisciplinary research (IDR) (also called convergence research) in order to spark innovative research and to address complex problems. Prestigious universities that have high revenues and investments in research and development, such as Harvard and Columbia, have higher structural commitment to IDR than technical universities like MIT and CalTech, perhaps due to a greater focus on spanning domains (industry, government and academia) than disciplines.

Today, America continues to support initiatives of researchers and of research institutions, and scientific productivity remained high. Today, China's ambitions are pushing the United States to redesign its research and development strategy, which has led the Biden administration to come up with a new research agenda with support close to $ 200 billion as part of a larger $2 trillion infrastructure spending plan. The White House notes that federal spending on R&D as a share of U.S. gross domestic product has fallen to about 0.7% from its peak of about 2% during the Apollo era. It states that the proposed plan will “unify and mobilize the country to meet the great challenges of our time: the climate crisis and the ambitions of an autocratic China.” It places an emphasis on engaging more of the country in the conduct of R&D, proposing an array of regional economic development programs and to boost America’s innovative edge in markets where global leadership is up for markets like battery technology, biotechnology, computer chips, clean energy. If it is voted into law by Congress, the US plan will provide:

- $50 billion to the National Science Foundation to support fundamental research and to initiate the creation of a “technology directorate” within the agency,
- $40 billion to upgrade research infrastructure in laboratories across the country. Half of the funds will be reserved for Minority Serving Institutions and a portion will go toward creating “a new national lab focused on climate.”
- $20 billion to create at least ten “regional innovation hubs” and a “Community Revitalization Fund”, to “leverage private investment to fuel technology development, to link urban and rural economies, and to create new businesses in regions beyond the high-growth centers.
- $14 billion for the National Institute of Standards and Technology to bring together industry, academia, and government to advance technologies and capabilities critical to future competitiveness.
- $31 billion to support programs that give small businesses access to credit, venture capital, and R&D dollars.
- $100 billion to upgrade the public school system, by equipping schools with “technology and labs” necessary to prepare students for “jobs of the future.”
- $15 billion toward demonstration projects for climate R&D priorities, including utility-scale energy storage, carbon capture and storage, hydrogen, advanced nuclear, rare earth element separations, floating offshore wind, biofuel/bioproducts, quantum computing, and electric vehicles.
- $50 billion to implement the recently enacted CHIPS for America Act and to monitor domestic industrial capacity and funding investments in support production of critical goods.
- $30 billion to support medical countermeasures manufacturing, research and development and related bio-preparedness and bio-security.

References: https://www.aip.org/fyi/2021/biden-proposes-over-200-billion-rd-infrastructure-plan

Key points for the USA are the following:

- Gross domestic R&D expenditures in the U.S. are still very high globally, but declining in comparison with China.
- Industry is the largest source of U.S. R&D dollars – and that is growing rapidly, where other sources of funding are stagnating – which means the share of U.S. R&D funded by industry is growing over time.

- The federal government's funding of basic research has been growing – but not quite as fast as its funding of applied research has been growing. Moreover, industry still spends more on applied research than on basic research, implying that basic research is by no means dead in the U.S. but applied research is becoming a bigger focus.

6. The Evolution in Basic and Technological Research Organization among recent members of the EU: The examples of Croatia (2013) and Poland (2004)

Anna Fabjianska and Vladimir Mrsa

6.1 The Example of Croatia

Croatia is the newest member that joined the European Union in 2013. Generally, the public research and innovation sector in Croatia is underfunded. The annual budget of Croatian universities allocated from public sources amounts to around 730 million Euro, while the budget of other public institutes reaches 133 million [1] for approximately 161,000 students in 2020. On top of it, universities have incomes from other sources (industry, local communities etc.). Altogether, the overall the income of Croatian universities does not reach 1 billion Euro per year, so that the highest figure for the expenditures per student that one may quote is 6,200 euros/year.

Compared to other EU members Croatia belongs to countries with the smallest share of GDP allocated to research and higher education. Research financing is particularly marked by low investments of the private sector. However, after its admission to the EU, the Croatian government invested significant efforts in improvements in the R&D area. Gross Domestic Spending on R&D (GERD) increased in the period 2015 to 2020 by 67% (in the same period the increase of GERD in EU28 was 16%) [2]. The measures taken by the governmental bodies resulted in a steady increase in the European Innovation Score since 2014 from 0.265 to 0.366 in 2021 resulting in a comparative shift of Croatia from rank 29 to 26 out of 38 European countries [3]. Indicators point out that Croatia is doing much better in the R&D expenditures in the public (ranked 18) than in the business sector (ranked 26). In spite of it, there is a pronounced trend of opening new SMEs (in 2021 Croatia is ranked 2nd in the category "Enterprise births", and 10th in "SMEs") [4] and demonstrates a slow but significant change of entrepreneurial climate in the country. At the same time, the administrative and bureaucratic burdens that hindered formation of start-ups and research-based companies in general have mainly been removed.

However, the relationship between the academic and the production sector is still not satisfactory. Researchers still tend to prefer research that would bring highly cited papers and recognition in the academic community than to move their focus to results with more direct application. Largely, it is a consequence of the academic promotion system that is basically metrics oriented. Younger researchers are particularly under pressure to publish. The state puts efforts in promoting collaboration between academia and the private sector mainly through financing joint projects but the level of financing allows research to the TRL levels not higher than 3 to 4. Besides, project budgets include only the salaries of young researchers that are fully employed through the project that is not stimulating for other participants. This all brings about a climate in which even research-oriented companies that have originated from academic projects and do well at the global market, do not maintain long-lasting relations to academic institutions and tend to collaborate with them only on very specific topics or problems. Thus, a better connection of the new knowledge-based companies and the academic sector requires a different approach in which the state would allocate higher budgets to research and higher education, particularly technology-oriented projects, more of which should reach TRL 7, or 8. On the other hand, criteria for elections and promotions of academic staff should be more flexible and oriented towards the research development strategies of individual research institutions. In this way the responsibility for quality assurance would be transferred from the state bodies (adopting national criteria) to universities (implementing their own criteria reflecting individual development strategies).

6. 1. 1. Research and higher education capacities

As a small country of roughly 4 million inhabitants Croatia has a higher education system comprising mainly public HEI including 12 universities (9 public, 3 private), 17 universities of applied science (11 public, 6 private), and 18 high schools (3 public, 15 private). Private higher education contributes with about 10 % of Croatian students, while 90% study at public HEIs[59]. Of about 163 000 Croatian students 30% study one of the study program in the STEM area. Most of Croatian research and higher education facilities are located in Zagreb with the University of Zagreb being the largest university in Croatia with more than 72 000 students and over 7000 teaching staff. Besides, the largest public institute "Rudjer Bošković" employs more than 500 researchers participating in various projects mainly in the areas of chemistry, biochemistry, molecular biology, biomedicine and physics.

6.1.2. Legislative framework for technology-oriented research

In Croatia, the development of technology-oriented research in the public research area in the last decade is based on three strategies brought by Croatian parliament.

- *The National Science, Education and Technology Strategy*[60] was adopted at the very end of 2014. The chapter dealing with research started with an analysis pointing out that the gross domestic expenditure for research and development undertaken in 2013 was low, and while it has been on the rise in most EU countries, it has been declining in Croatia. The share of the business sector was much too low and far below the European average. In order to rectify this situation, a general refocusing of expenditures towards research and innovation, and towards small and medium-sized enterprises was assessed as essential. Therefore, incentives and support to strengthen the role of small and medium-sized enterprises in research, development and innovation, were introduced, while this role was maintained in large enterprises.

The establishment and growth of innovation enterprises was set as priority, and cooperation and joint projects between the business sector and public universities and public institutes were to be fostered. The growth of investments of the business sector in external services of R&D and in the acquisition of external knowledge had been foreseen to depend on the competitiveness of the higher education and research community, as well as on state measures for strengthening research, development and innovation. What was assessed particularly relevant was research and cooperation related to societal challenges that largely overlapped with the work of public enterprises, community organisations and state institutions.

- *The Smart specialization strategy* includes two specific strategic goals. The first defines the increase of the capacity of the science-research sector for executing high quality research that reflect the needs of the economy, while the other points out modernization and diversification of Croatian economy through investments of the business sector in research, development, and innovation. The

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[59] https://www.azvo.hr/en/higher-education/higher-education-institutions-in-the-republic-of-croatia
[60] chrome extension:
//efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fmzo.gov.hr%2FUserDocsImages%2F%2Fdokumenti%2FObrazovanje%2F%2FStrategy%2520for%2520Education%2C%2520Science%2520and%2520Tehnology.pdf&clen=1355391&chunk=true

thematic areas on which Croatian research should focus were defined as *Health and life quality, Energy and sustainable environment traffic and mobility, Safety*, and *Food and bio-economy*.[61]

- *The National innovation strategy* also defined two strategic goals, one as the incentivizing co-operation and knowledge stream between the business, public, and research sectors, and the other directed to strengthening human potential for innovation and creation of supportive environment for internationally competitive researchers[62].

In conclusion, all three strategic documents clearly defined the need for intensifying collaboration between universities and public institutes on one side and the production and service providing organizations on the other. Initiative in the development of collaboration was on the side of the governmental bodies and should have been achieved by incentive financing of joint projects. Different programs have been outlined providing budgets for research oriented technology development for one, or both partners in the project. Strategies also pointed out that strengthening of capacities of institutional support of technology transfer was required.

6.1.3. Institutional support of technology-oriented research

The main funding bodies related to technology-oriented research, in addition to the Ministry of Science and Education, are the Croatian Science Foundation (CSF) funding different programs, research projects and reforms of universities, and the Croatian Agency for SMEs, Innovations and Investments (HAMAG-BICRO) supporting various innovation policy programs and creating, implementing and financing innovation policy programs for the commercial application of science. Since Croatia's admittance to the European Union, through the *Regional Competitiveness Operational Program* and the *Operational Program Human Resources Development*, Croatia has been combining European Regional Development Fund (ERDF) and European Social Fund (ESF) for funding development of science and research. *The Unity for Knowledge Fund* (UKF) was established by the Croatian government in 2007 to support programs for fostering cooperation between home and expatriate scientists.

The Croatian Agency for SMEs, Innovations and Investments (HAMAG-BICRO) provides support to knowledge-based SMEs through strengthening competitiveness by investments in digital and green transition. They also coordinate Eureka program for the support of micro, small, medium, and large enterprises to international co-operation in starting R&D activities. The main goals of HAMAG-BICRO are to provide incentives to companies who invest in R&D activities and strengthen their innovation capacity, to foster international collaboration of entrepreneurs, and to provide fundaments for international market placement. Universities and public research institutes can join these projects only as external collaborators but not as project leaders. The share of the project covered by the incentives depends on the size of the company but it can amount up to 200 000 EUR[63].

The BICRO-BIO Centre is a specialized biotechnology research-technology unit that operates through five different programs. The main intention of these programs is to provide offices, laboratories, and consultancy for start-ups and established biotech companies, connect biotech companies, start-ups, universities and institutes, situated either locally in Croatia, or abroad and to provide necessary networking capacities, and to provide services of the Central Laboratory Specialized Units

[61] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fs3platform-legacy.jrc.ec.europa.eu%2Fdocuments%2F20182%2F222782%2Fstrategy_EN.pdf%2Fe0e7a3d7-a3b9-4240-a651-a3f6bfaaf10e&clen=4657547
[62] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=http%3A%2F%2Feuropski-fondovi.eu%2Fsites%2Fdefault%2Ffiles%2Fdokumenti%2FStrategija%2520poticanja%2520inovacija%252020 14-2020.pdf&clen=5192835&chunk=true (in Croatian)
[63] https://en.hamagbicro.hr/

(Microbiology, Cell biology, Downstream processing, Proteomics and Bioanalytical chemistry)[64].

Several University/faculty technology transfer centres and units in larger faculties of the universities in Zagreb, Rijeka, and Split have founded technology transfer centres as independent units owned by the university or the faculty with the aim to promote technology-oriented research and foster creation of start-ups, and collaboration between the faculty staff and SMEs.
As an example, the *Center for Technology Transfer* is a company founded already in 1996 by the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, with the support of the Ministry of Science and consulting from the German Fraunhofer Institute.

In addition, the *Innovation Centre Nikola Tesla* is an institution founded by the Faculty of Electrical Engineering and Computing, University of Zagreb with the same purpose. Similar centers have also been founded by the University of Zagreb, University of Rijeka, and University of Split, but they provide mainly advisory and intellectual property help.

6.1.4. State-of-the-art and perspectives

It is worth noting that the panorama we describe today largely resembles the situation in the Croatian higher education system in the 60's and 70's when basic research was very poorly financed and burdened with many administrative obstacles. Nevertheless, Croatian academic institutions were directly involved in the setup and development of several Croatian large industrial companies that were productive and economically very successful in the following decades.

6.2 The Example of Poland

6.2.1. The structure of Polish R&I system

The research and innovation (R&I) system in Poland is governed and formed by the central government, with the responsibility for managing the R&I system borne mainly by three ministries: the Ministry of Economic Development, Labor and Technology (MRPiT), the Ministry of Education and Science (MEiN), and the Ministry of Funds and Regional Policy (MFiPR). The actions of ministries are synchronised by the Council for the Innovativeness. The Council is the main interdepartmental platform that serves as advisor to the goverment and coordinator of innovation policies implemented by the state. The council is integrated into the public administration system.
The MEiN, whose remit includes higher education, is responsible for developing research strategies for both applied and basic research. It is advised by the Committee for Science Policy (KPN), an auxiliary body of the competent minister, which advises on the preparation and implementation of the state science, research and innovation policy and assists in the preparation of the draft state science budget. The Committee also issues opinions on draft normative acts on the development of science and innovation, on the activity plans of the government's research funding agencies and assesses and reports on their activities. MRPiT designs and implements the innovation policies. MFiPR oversees the use of the European Structural and Investment Funds (ESIF). Respective Ministries also supervise funding agencies.

The key governmental R&I funding agencies include National Center for Research and Development (NCBR, est. 2007), and National Science Center (NCN, est. 2011). NCBR is the largest innovation support center in Poland, which implements the state's science, technology and innovation policies, including strategic, national and international programs. It is an intermediary body of MEiN for operational programs funded by EU funds. NCN supports exclusively basic research and provides funding for all fields of arts and sciences (arts, humanities and Social Sciences, Life Sciences and

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[64] https://www.biocentre.hr/en/

Physical Sciences and engineering) researchers at all stages of their careers (from PhD students to experienced professors). The efforts of govermental funding agencies are complemented by The Foundation for Polish Science (FNP, established in 1991), an independent and self-financing Polish non-profit non-governmental institution. It is the largest extra-budgetary source of funding for science in Poland. Since 2008, FNP has supported research and innovation through the implementation of programs funded European Structural and Investment Funds (ESIF).
Bussiness investments in R&I at the govermental level are supported by the Polish Development Fund (PFR, est. 2016) which is a state-owned financial group that provides instruments to support the development of businesses, local authorities and individuals, and invests in sustainable social development and national economic growth. PFR's mission as a Polish promotional financial institution is to implement programs to increase long-term investment and economic potential, as well as to promote equal opportunities and environmental protection. The members of the PFR group are the Polish Agency for Enterprise Development (PARP, est. 2000) and Industrial Development Agency S.A. (ARP, est. 1991). PARP is a state legal entity (executive agency) reporting to the Minister in charge of Economy. It manages funds from the state budget and European Union, which are earmarked for supporting small and medium-sized enterprises and human resources development. ARP is a joint stock company of the State Treasury, which supports the restructuring of Polish enterprises.

In addition to the central level, each of Poland's 16 regions (voivodeships) has its own R&I budget (smaller than the ones offered on a central level) based on European Structural and Investment Funds (ESIF). Through the Marshal's Office in each region, regions manage the funds from Regional Operational Programme according to the region-specific objectives. The latter, defined by Regional Smart Specialisations (KIS), aim at boosting and promoting regional development according to local needs and thus vary between regions. The regions adapted various approaches to their implementation, monitoring and evaluation. Most regions have set up Regional Development Foundations but there is no uniform strategy. Some regions and large cities also support specific initiatives to improve networking between public and non-public R&I actors, e.g. science and technology parks.

6.2.2. Research and technology capacities

Research and development activities in Poland are performed by both public and private sector institutions. The main R&I actors in Poland include Universities, institutes of the Polish Academy of Sciences, research institutes, and other organizational units like R&D centers or science & technology parks. Most research in Poland is conducted at public universities, which additionally fulfil the educational mission. There are currently 373 universities in Poland (of which 134 are public, i.e. state-funded). Universities are mostly under the supervision of the Minister of Education and Science. Some of them are additionally supervised by other competent ministers (e.g. the Ministry of Health, the Ministry of National Defence and the Ministry of Culture). Recently, the Polish Ministry of Science and Higher Education nominated 10 most research-active universities, which, following the evaluation of a panel of international experts, were granted the status of research universities and awarded 10% additional funding. Another 10 universities were also recognised for their scientific achievements and received a 2% increased budget to enhance their research excellence. Depending on their profile, the universities are involved in both basic research and research and development. Many of them have established technology transfer centres to assist researchers and students in exploiting their research results and other entrepreneurial and innovative activities. The centres act as a link between the university and external organisations and support commercial activities and IPR.

Another group of research units are the institutes of the Polish Academy of Sciences (PAS). There are 69 PAS institutes in total, grouped into five faculties (I - Humanities and Social Sciences, II - Biological

and Agricultural Sciences, III - Natural and Earth Sciences, IV - Technical Sciences, V - Medical Sciences). Their mission is to conduct high quality research in key areas and to disseminate and exploit the scientific results, with most of the budget allocated to basic research. The institutes also run postgraduate programmes and doctoral schools. The institutes of PAS conduct mainly basic research, but several percent of their activities are devoted to research and development (especially in the faculties of engineering and medical sciences). Most of the institutes of PAS are leaders in their scientific or R&D activities, with 14 of them ranking highest in the institutional assessment.
Apart from the institutes of the Polish Academy of Sciences, there are also research institutes, that are important RTO organizations in Poland and are essential for building a knowledge-based economy. Currently, there are 103 research institutes in Poland. The vast majority of them operate in the fields of science and engineering, and life sciences. The basis of their activity is the Act of 1985, amended several times in the following years (i.e., 1991-2010) and replaced by the latest Act of 30 April 2010 with further amendments (Journal of Laws 2020, item 1383), which defines the current legal and organizational framework of research institutes. According to this Act, a research institute is a governmental organizational unit with a legal personality that differs in administrative, economic, and financial terms. It conducts scientific research and development work aimed at their implementation and application in practice. Thus, the main activities of the Institute include conducting research and development work, adapting their results to the needs of the practice, and putting them into practice[65].

Initially, the network of the R&D institutes in Poland mirrored the industrial structure of the Polish economy in the Communist period. It didn't change immediately, even after Poland's accession into the European Union. Only the 2010 reform restructured and consolidated the institutes, reducing their number by about half (compared to 267 in 1990). The research and development units were transformed into research institutes subject to strict control rules and systematic audits. They are supervised by the competent ministers (at most the Minister of Economy). The Science Evaluation Commission also assesses their research and development activities in the Ministry of Science and Education.

According to Supreme Audit Office (NIK)[66], after the 2010 reform, the number of patents in research institutes doubled in 2013. However, the number of practical implementations of the developments decreased by 20%, similarly to the revenues from the sale of scientific research and development work. In 2019[67], only 11.5% of research institutes' revenues were from the sale of scientific research and development work (i.e., the impact of their core activities). The sale of patent rights and licenses for the use of inventions and utility models generated 0.12% of revenue for only one Institute (out of eight audited). The model for the functioning of research institutes in Poland set out in the 2010 Act does not appear to be sufficiently effective in boosting the innovation and competitiveness of the national economy. As the NIK states in its 2019 report, the reason could be that the institutes defined development directions, posed challenges, and identified problems to solve. Their main goal was not to contribute to national economic development but to maximize their revenues.

In order to mitigate the above limitations and strengthen the R&D activities of research institutes towards the knowledge economy, the Łukasiewicz Research Network (ŁRN) was established on 1 April 2019 to link science and business and consolidate some of the institutes. With 32 research institutes in twelve cities and more than eight thousand employees (including 4.5 thousand researchers and engineers), the Łukasiewicz Research Network is the third largest research network in Europe. It also collaborates with business partners, including IKEA, Airbus, Boeing, Siemens, ABB. The Łukasiewicz Center is responsible for research planning and coordination of the individual

[65] https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20200001383
[66] https://www.nik.gov.pl/aktualnosci/nik-o-instytutach-badawczych.html
[67] https://www.nik.gov.pl/aktualnosci/nik-o-gospodarce-finansowej-instytutow-badawczych.html

institutes. The institutes of the network aim to conduct research (also internationally) and commercialize their results. In the years of 2019-2020, on average, 13,5 % of the ŁRN revenue was Research commercialization and 28,5% income from the R&D activity[68]. The institutes affiliated with ŁRN may also produce unique research equipment and materials, perform metrological, standardization, and certification activities, develop prototypes of new technological solutions, conduct courses and personnel training for industry, and, if necessary, other activities related to their essence.

An essential aspect of the functioning of the institutes is their activity for the benefit of society. Therefore, one of the tasks of the institutes is the popularization of science and knowledge of new technologies. More than 120 employees of the ŁRN have been performing doctoral research within a framework of an implementation doctorate – an alternative way to obtain the doctoral degree introduced in 2017 and intended for people who - to develop their scientific career - do not want to give up their professional activity outside the university. The main assumption is to do a doctoral research that serves the functioning of a particular business by solving a particular technological problem. It supports the writing of doctoral dissertations by doctoral students who conduct research whose results can be used in the activities of a company. The preparation must not take more than four years.

In Poland there are also research and development centers - companies that are not research institutes and that carry out research and development. R&D center status can be obtained from the Ministry and brings special benefits in terms of tax relief and some exemptions. CBRs provide technical and scientific support to industries such as pharmaceuticals, medicine, energy, mining machinery production, IT and the engineering sector. There are currently 38 CBRs in Poland. Industrial and technology parks (technoparks) also play an important role in regional development in supporting entrepreneurship and the development of the innovation economy. These are a set of separate properties with technical infrastructure (some of which originate from restructured or liquidated companies) created for knowledge and technology transfer between research units and entrepreneurs. Currently, there are about 80 technoparks in Poland, the first of which was established in Poznań in 1995. The vast majority of parks were established by local government units (city or municipality), often in cooperation with universities from the respective area. A small percentage is the result of the investment of private capital, e.g. the Płock Industrial and Technological Park as a cooperation between Orlen and the City of Płock or the first fully private technology park YouNick Technology Park in Wielkopolska.

6.2.3. Institutional support of technology-oriented research

The main institution that supports and funds the implementation of research and development projects arising from the state's science and innovation policy is the National Centre for Research and Development (NCBR). The main source of funding for entrepreneurs is the Innovative Economy Operational Programme (2007-2013, EUR 10 186.030 million) and the Intelligent Growth Operational Programme (2014-2020, a total of EUR 10 189.8 million, of which EUR 8 613.9 million from the EU), financed by the European Regional Development Fund. Its main role is to increase business spending on R&D and improve the conditions for their R&D activities. It is intended for larger scale projects with a minimum level of innovation developed nationwide. In the coming years (2021-2027), the European Funds for a Modern Economy programme is expected to provide Poland with an additional EUR 7.9 billion to support the increase of research and innovation potential and the use of advanced technologies, increase the competitiveness of SMEs, develop skills for smart specialisation, industrial transformation and entrepreneurship, and support the transformation of the economy towards Industry 4.0 and green technologies.

In addition to the national funds offered by the NCBR, voivodeships in Poland can take advantage of the Regional Operational Programmes (ROP). Each region has identified the main development needs for an individual ROP, which determine the different regional support. Nevertheless, all voivodeships support the increase of research and development activities of enterprises and their expenditures on R&D infrastructure. ROP co-financing refers to R&D projects and investments carried out on a smaller scale than under national funds.

EU funds have also played an important role in the development of industrial and technological parks in Poland. In 2004-2014, PLN 840 million was allocated from European funds for the creation of infrastructure for technology parks. Also within the framework of the EU perspective 2014-2020, technoparks received funds for the preparation of areas.

6.2.4. State-of-the-art and perspectives

According to Eurostat, in 2020 the gross domestic product (GDP) in Poland was 479,895 mil. Euros with 12,680 euros per capita. Although this value is visibly below the EU average, it has been predominantly increasing for at least the last 20 years. According to the Central Statistical Office of Poland, gross domestic expenditure on R&D in Poland almost tripled in 2010 -2019 - from PLN 10.4 billion to PLN 30.3 billion. During this period, a constant annual increase was observed (with the exception of 2016, when a decrease of 0.7% was observed compared to the previous year). Also, the real GDP growth-rate volume in Poland has been however higher than the EU average, in 2019 scoring 5.4, compared to 2.0 being the EU average. The average increase in spending on R&D activities during this period was 12.8% with a maximum in 2018 with an increase of almost 25%. In 2019, Poland's spending on R&D activities increased by 18.1% compared to the previous year. The ratio of R&D expenditure to GDP increased from 1.21% to 1.32% in this period, but was still below the EU average (2.11% in 2019) and still below the 1.7% defined in the National Reform Program for the implementation of the Europe 2020 Strategy, adopted by the Council of Ministers on 26 April 2011.

Out of the total PLN 30.3 billion spent on R&D, companies and institutions spent over PLN 5 billion on investments in 2019. More than half (50.7%) of R&D spending was financed by the business sector. The state sector financed 38.8%. Spending by the higher education sector amounted to only 3%. Of this, PLN 19 billion was spent on projects by companies, PLN 10.8 billion on academic work, PLN 384.2 million on state institutions and PLN 90.3 million on private non-profit institutions. In 2019, spending in almost all areas increased compared to 2018. The number of people employed in research and development increased by 1.8% compared to the previous year and stood at 271,000 in 2019. Employment, expressed in full-time equivalents (FTEs), was nearly 164,000, with the majority, 79.3%, being internal employees of companies and institutions. Since 2014, the number of institutions engaged in R&D has been growing annually; in 2019, there were 5,860 organizations. The increasing interest of the business sector in R&D investment may be partly caused by the R&D Tax Incentives introduced in Poland in 2016, which aims to encourage entrepreneurs to engage in R&D activities and stimulate the creation and development of innovations. In particular, this includes the volume-based R&D tax relief and the IP Box relief. The cost of this support was PLN 39 million in 2016, rising to PLN 308 million in 2018[69]

Since 2019 Poland has ranked 24th out of 27 countries in the European Innovation Scoreboard. In 2019 and 2020 it was classified as a moderate innovator, while in 2020 – as an emerging innovator. However, the scores continue to improve. Although Poland's overall ranking did not improve either

[69] OECD (2021). "R&D Tax Incentives: Poland, 2020", www.oecd.org/sti/rd-tax-stats-poland.pdf, Directorate for Science, Technology and Innovation, March 2021.

in 2020 nor 2021, over time, Poland's performance relative to the EU has increased strongly. Between 2014 and 2021 Poland's innovation performance improved 14.6%-points which was above the EU's average of 12.5% points. Poland observed a close to 5%-point annual increase in performance since 2019.

It should be noted that in 2021 the report found that the performance increase in the last two years is mostly due to strong improvements in product and business process innovators, broadband penetration, employment in innovative enterprises and public R&D expenditures.