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European Research Projects on Quantum Technologies and High Performing Computing: Analysis of The Communication Strategies

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Abstract

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Part I

Introduction

Chapter 1

The role of science communication

This chapters presents a concise overview of the importance of science communication in modern society. Section 1.1 outlines the characteristics of the knowledge era. Section 1.2 focuses on the related economical and societal challenges. Section 1.3 highlights the need for scientific citizenship in the knowledge era. Section 1.3 presents science communication as a requirement for scientific citizenship.

1.1 The knowledge era

Three economical eras have been identified in the history of human civilisation. The first one was the agricultural era. This is believed to have started between 10000 and 8000 B.C. in different regions in the world [1,2]. The second one is the industrial era. It began in England in the 18th century as a result of the industrial revolution [3,4]. The third one is the knowledge era, and it is the age into which human civilization is currently entering [5].

The three eras are based on different primary production resources. The agricultural age was founded on the work of people and animals. The ultimate source of richness and development in the industrial era was the work of people and machines. Finally, the current era is not based on the capacity to produce and accumulate tangible goods, but rather on the ability to store, generate and apply new knowledge [6].

The information on which the current era is based is mainly scientific. In the past centuries, the impact of science on humanity has been growing without interruption [7]. Nowadays, the outcomes of scientific activities permeate our society and heavily shape our life style. Examples range from telecommunications to medicine, or from artificial intelligence to the development of new materials.

The reason for the increasing impact of science is the peculiar nature of scientific knowledge as a resource [8]. Just like any other resource, it is important for its capacity to provide solutions to problems. However, contrarily to resources such as water, food or oil, scientific knowledge is potentially unlimited, as it is capable of generating itself (knowledge leads to new knowledge). Moreover, the same knowledge can be used simultaneously by multiple entities. Hence, scientific knowledge is intrinsically a non-exclusive good.

For its characteristics as a resource, scientific knowledge has revolutionised the world economy. The current science-driven change of the global market has introduced countless positive innovations. However, it has also led to dramatic societal changes.

1.2 Challenges in the knowledge era

The relationship between scientific research and society has changed significantly after the second world war. From the second half of the 20th century, several countries have started using science and its generation of new knowledge and technology as a source of economical growth. This process has progressively become more intense over the last decades. Nowadays, nations invest significant fractions of their gross domestic product in research and development. Examples

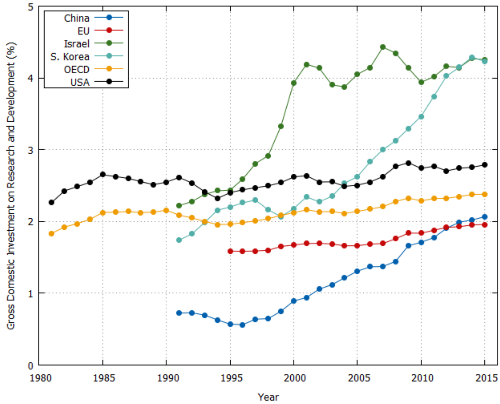

Figure 1.1: Gross domestic percentage invested in science and development over the past years by some of the world's leading economies. The image is based on data of the Organisation for Economic Cooperation and Development (OECD) [9].

are the European Union, the United States, and Asiatic countries such as China and South Korea, see figure 1.1.

The capacity of scientific knowledge to generate richness has attracted a growing number of private investors. As a result, in many countries private investment on scientific research is larger than public funds [10]. One example are the United States, where the former is currently twice as large as the latter [11].

The leading role of private investors is based on a reinterpretation of knowledge as a resource. To pursue personal profit, investors are typically non interested in sharing the knowledge they develop or they way they use it to create goods. This approach limits the possibility to generate new knowledge from the results of others. Moreover, people with limited buying power cannot afford specific classes of products and benefit from the knowledge behind them. One ex-

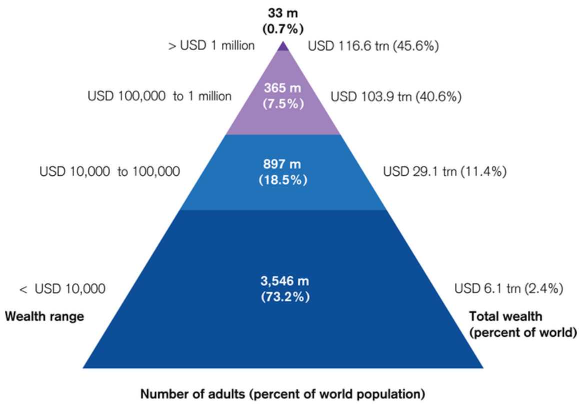

Figure 1.2: Distribution of the global wealth among the world's population. Original image in [12].

ample are patented expensive medicines [13]. In such a scenario, knowledge as a resource partially looses the intrinsic characteristics mentioned in Section 1.1 of being unlimited and non exclusive.

The current knowledge-driven development of the global economy has two important consequences. Firstly, humanity is richer than ever before [14]. Secondly, the progressive concentration of the generated richness in the hands of few individuals is causing societal inequality, see figures 1.2 and 1.3.

The increasing inequality is an obstacle for the creation of a democratic society [15]. The scenario humanity is facing can change if knowledge will not be used as a mere instrument of power, but rather as a common good everyone should benefit from. This paradigm shift can be achieved through the acquisition of the scientific citizenship.

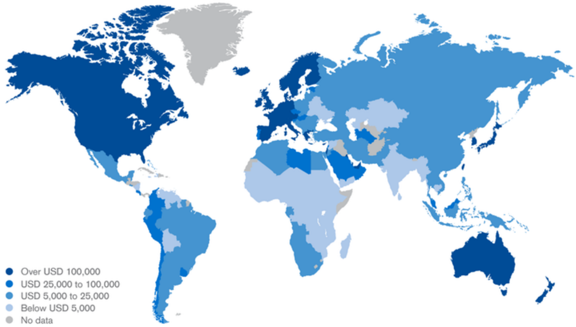

Figure 1.3: Comparison among nations of the current annual wealth per adult. Original image in [12].

1.3 The scientific citizenship

The potential of scientific knowledge to be a pillar of democratic societies was first recognised by English philosopher Francis Bacon in the 17th century. He proposed that science and technology should not bring advantages to a limited number of societal groups or nations, but rather to the whole humankind [16]. This vision is efficaciously outlined in his utopian novel *The New Atlantis*.

Bacon's ideas are extremely topical. As mentioned in section 1.2, the equal access to goods generated by scientific research is fundamental to prevent societal divisions and exclusions.

A second ingredient for the creation of a democratic society is the people's awareness of the scientific process, as well as of its goals, outcomes and limits [17]. In fact, democratic societies are founded on the engagement of citizens when decisions impacting the community must be taken. Because of science permeating role in today's society, science-related issues are no exception [18]. Examples are topics such as mandatory vaccination, euthanasia, abortion, animal experimentation, alternative medicine, nuclear energy, recycling and, in general, the public investments on research assigned by policy makers. Hence, a better understanding of science is a key factor to ensure effective participatory processes [19].

The population's engagement in decision-making processes is only fruitful if scientific innovations are neither passively accepted nor irrationally feared. To this aim, people must be given the ability to intervene in an informed, rational and critical way. This scenario is only possible if individuals are formed and trained in an adequate cultural context. In other words, if people acquire the so-called scientific citizenship [20].

How to best prepare individuals to become scientific citizens is still debated [21]. Nevertheless, a key ingredient has been identified in the need to bring scientists and citizens closer to each other. It is widely accepted that the construction of a democratic knowledge era depends crucially on the continuous dialogue and information and knowledge exchange between these two communities. A paradigm which motivates the growing importance of science communication.

1.4 Science communication and modern society

Science relies heavily on communication. To be useful, research results must be communicated to the rest of the scientific community. This has become even more crucial in the era of Big Science [22]. Modern physics offers illustrative examples in this direction. Large-scale experiments such as the LHC particle accelerator at CERN in Switzerland or the LIGO-Virgo gravitational-wave observatories in the USA and Italy are built and maintained by international collaborations of thousands of scientists from tens of different countries [23–25]. These titanic efforts can only be successful if supported by effective internal communication.

The relationship between science and communication has evolved with the transition to the knowledge era [26]. Nowadays, science communication can no longer happen exclusively within the scientific community. As outlined in Section 1.3, the construction of a democratic society requires the engagement of disparate societal groups in the decision-making processes related to scientific questions [27]. Examples are scientists, policy makers, private investors, non-governmental organizations, citizens etc. Hence, when discussing with each other, these groups make use of science communication.

The aforementioned societal groups have different cultural background and objectives. Thus, they adopt different languages when talking about scientific issues. Moreover, to be effective, each group must tune its science communication on the targeted audience, with the optimal choice depending on both the content and considered communication channel. As a consequence, numerous different kinds of science communication can be identified.

The present thesis focuses on science communication aiming to inform citizens on a non-technical level of current investigation lines. This is the oldest type of science communication not confined within the scientific community. The first example in this direction was the *De Rerum Natura* by Roman poet Lucretius in the first century BC. Another historically very important book was Galileo Galiei's *Sidereus Nuncius* in the XVII century. His work rapidly spread all over the world short after publication and revolutionised humanity's self-perception by propagating the author's innovative astronomical discoveries [28].

More specifically, this thesis focuses on a specific class of EU-funded research project and on their use of the web 2.0 social media to communicate results and objectives. As outlined in the next chapters, the ultimate goal is to investigate whether European scientists are properly exploiting today's most effective communication channels to inform citizens of two of the future's most important scientific challenges: the development of quantum technologies and high-performing computers.

1.5 Chapter summary

In this chapter, the following items have been discussed:

1. Human society is currently entering the so-called knowledge era. This age is characterised by the fact that scientific knowledge has become one of the most important sources of wealth.

2. The knowledge era offers unprecedented opportunities to improve people's life quality. However, it also presents new challenges. In particular, the unequal access to scientific knowledge and technology may prevent the realisation of democratic systems.

3. The construction of a democratic society in the knowledge era depends on the engagement of citizens and stakeholders in the debate on the impact of scientific issues on their lives. This can be achieved by training people to discuss scientific questions in a constructive and critic way, i.e., if individuals acquire the so-called scientific citizenship.

4. One key factor to help people acquire the scientific citizenship is science communication. There exist disparate kinds of science communication, depending on the interacting societal groups. The present thesis focuses on science communication adopted to inform citizens via social media of recent developments in European research projects.

Chapter 2

FET in Horizon 2020

This chapter focuses on the FET funding programme. Section 2.1 illustrates the Horizon 2020 initiative. Section 2.2 is a description of FET in the framework of Horizon 2020. Sections 2.3 and 2.4 summarise the FET effort towards the development of quantum technologies and high-performing computers, i.e., the two most important research lines for the scope of this thesis.

2.1 The Horizon 2020 programme

Horizon 2020 is the biggest Research and Innovation programme funded by the European Union to date. It targets a smart and sustainable societal and economic growth via the development and application of scientific research. The available budget totals nearly €80 billion over a seven-year period (from 2014 to 2020) [29].

Horizon 2020 is Europe's eighth Research and Innovation programme in chronological order [30–33]. The first was launched in 1984. Duration and allocated budget of each Research and Innovation programme are shown in figure 2.1.

Any natural or legal persons (e.g. universities, research organisa-

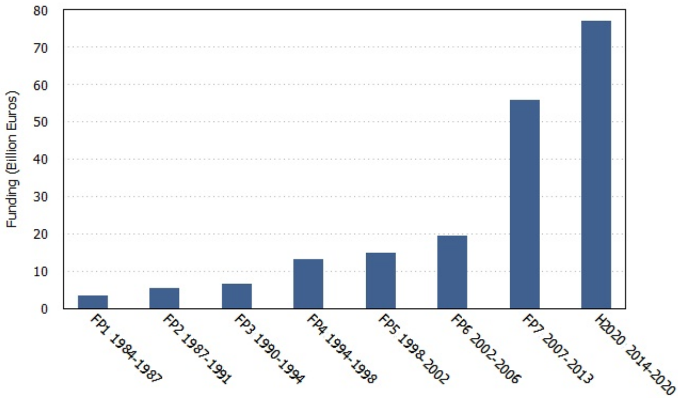

Figure 2.1: Duration and allocated budget of Europe's Research and Innovation programmes (also known as Framework Programmes, FP). Budgets are expressed in billion Euros. Data from [34].

tion and companies) can apply for Horizon 2020 funding. The main categories into which applications must fit into one of the following categories:

- **Excellent Science:** this initiative supports the excellence of European scientific research on a global level and in a variety of fields [35].
- **Industrial Leadership:** this class of projects targets the development of technological innovations for the future market and the growth of European small and medium enterprises [36].
- **Societal Challenges:** this category focuses on priorities of the European society such as health, education, energy supply and food by combining knowledge and methods from disparate scientific fields [37].

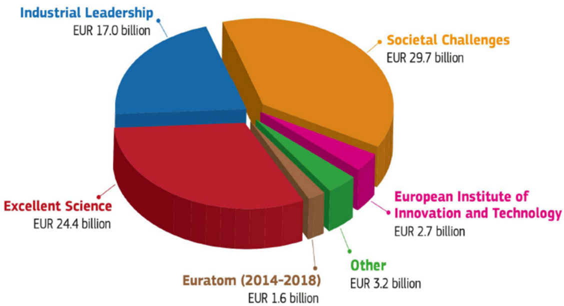

Figure 2.2: Budget breakdown of the Horizon 2020 programme. Original image in [40].

- **European Institute for Innovation and Technology:** this institute is an independent European body supporting growth via the promotion of synergies in the fields of education, research and business [38].
- **Euratom:** this pillar funds nuclear research in the framework of the decarbonisation of the energy supply [39].

The Horizon 2020's budget breakdown into the aforementioned lines of action is shown in figure 2.2.

2.2 The FET programme

As mentioned in section 2.1, one of the actions of Horizon 2020 is the Excellent Science programme. This initiative supports researchers and institutions developing new science and cutting-edge technology. The goal is to keep European research at the forefront of scientific innovation and discover applications to improve the citizens' life and ensure economical growth.

Line of action	Estimated final budget
ERC	13.1
FET	2.7
MSCA	6.2
RI	2.5

Table 2.1: Estimated final budget breakdown of the Excellent Science initiative. ERC stands for European Research Council; FET for Future and Emerging Technologies; MSCA for Marie Skłodowska-Curie Actions; RI for Research infrastructure. Budgets are in billion Euros. Data from [40].

Excellent Science is based on the following pillars:

- **European Research Council:** it distributes funding in every research field to single scientists and with the requirement of scientific excellence [41].
- **Future and Emerging Technologies (FET):** it finances collaborative research exploring visionary and radically new investigation lines [42].
- **Marie Skłodowska-Curie Actions:** this initiative assigns grants to researchers at any stage of their career and encourages mobility between countries and fields of expertise [43].
- **Research infrastructure:** it promotes the creation of transnational networks of research infrastructures as well as the training of qualified staff [44].

The estimated final budget breakdown of Excellent Science is reported in table 2.1.

This thesis focuses on the communication activity of the 151 FET projects funded to date within Horizon 2020. The list of these

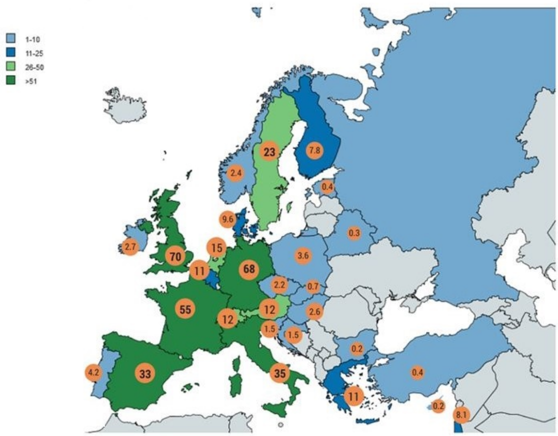

Figure 2.3: Participants in the Horizon 2020 FET programme on a country basis as of June 2016. Numbers correspond to FET funding in million Euros. Colours indicate the number of participants. Adapted from image in [45].

projects is available in appendix A. The distribution of projects participants per country as of June 2016 is shown in figure 2.3.

The FET funding scheme comprises three calls for applications: FET Open, FET Proactive and FET Flagship [46–48].

FET Open

The FET Open call is not bound to one specific investigation theme. However, submitted research proposals must satisfy the following "gatekeepers": scientific and technological breakthrough; foundational; novelty; high-risk; long-term vision; interdisciplinary.

FET Open promotes the Coordination and Support Actions (CSA) as well. These aim at identifying and fulfilling the optimal conditions for FET-related collaborative investigation. One CSA type of action is FET Innovation Launchpad, which investigates and explores possible economical and societal applications of FET results [49]. The list of Horizon 2020 projects funded within the FET Innovation Launchpad action is reported in appendix B.

FET Proactive

The FET Proactive call nurtures the birth of synergies on specific research lines by bringing together scientists from interdisciplinary fields. Considered research lines are not ready for the market yet.

Currently, FET Proactive comprises three calls related to "Boosting emerging technologies" and three under "High Performance Computing". Given its relevance for this thesis, the "High Performance Computing" FET Proactive call is illustrated in section 2.3.

FET Proactive invests resources also on identifying investigation roadmaps, design and distribute material for educational purposes and disseminate FET results among interested stakeholders.

FET Flagship

FET Flagships are Europe's main research effort. They are large-scale, decade-long projects with budgets totalling one billion Euros each. The ultimate goals are to shed light on key scientific themes and apply the results to European society. To date, three FET Flagships have been approved in the Horizon 2020 programme:

- **Human Brain Project:** it targets groundbreaking steps forward in neuroscience [50].
- **Graphene:** it explores graphene's properties and possible applications [51].
- **Quantum Technologies:** it aims at developing innovative technologies based on the laws of quantum physics.

The Human Brain Project and Graphene Flagships started in April 2016. The Quantum Technologies Flagship will start in 2018. Given its relevance for this thesis, the Quantum Technologies Flagship is described in section 2.4.

2.3 FET and high-performing computing

Current and future scientific and engineering challenges require increasing levels of computational performances. The demand can be satisfied via the construction of large computer clusters and the development of suitable programming languages. The former provide higher computational power for parallel calculations, the latter an optimal exploitation of the clusters' resources. The use of such practices is known as high-performing computing (HPC) [52].

In terms of increasing computational power, one major HPC goal is the transition from the peta- to the exascale. This corresponds to the increase from 10^{15} floating point operations per second, i.e. the limit of present-day most powerful supercomputers, to 10^{18}. The upgrade to the exascale is motivated by its major impact on all scientific fields, as it would push forward research and the development of new technology over the next decades [53].

As mentioned in section 2.2, the European HPC effort is funded within the "High Performance Computing" FET Proactive call [54]. This call comprises three initiatives: *i*) co-design of HPC systems and applications; *ii*) transition to exascale computing; and *iii*) exascale HPC ecosystem development. The main goals of the three initiatives are to develop the next-generation high-performing computers towards exascale and to provide access to the resources offered by supercomputers. The list of Horizon 2020 FET projects active in HPC is available in Appendix B.

2.4 FET and quantum technologies

Quantum technologies arise from applications of quantum physics. They are an important research topic on a global level for their potential to revolutionise human societies.

The so-called first quantum revolution started at the beginning of the past century with the development of quantum theory. The growing understanding of the atomic world led to the birth of new disciplines, such as informatics and microelectronics, and to the construction of countless fundamental tools and electronic devices. Examples range from computers and cameras to lasers and photocopy machines. The first quantum revolution played a key role in starting the knowledge era of human society.

It is believed that the second quantum revolution will be driven by the ability acquired by humankind to actively engineer the quantum world to its own purposes [55]. This is expected to lead to a complete new class of technologies which would reshape our society. One example is the development of quantum computers. If successfully developed, such machines will be far more powerful than any present and future computer based on classical architectures [56]. The urge for Europe to stay at the forefront of the second quantum revolution is outlined in the so-called Quantum Manifesto [57].

The development of quantum technologies is a central objective of the FET programme. The list of Horizon 2020 FET projects in this field is reported in Appendix B. Their activity is supported by the ERANET Cofund in Quantum Technologies, a FET Proactive initiative fostering synergies and partnerships among researchers and other stakeholders [58]. Finally, as mentioned in section 2.2, one dedicated flagship initiative will be launched in 2018.

2.5 Chapter summary

In this chapter, the following items have been discussed:

1. Horizon 2020 is the largest research funding programme of the

European Union. It is planned to run from 2014 to 2020 and has a total budget of nearly €80 billion.

2. One funding scheme of Horizon 2020 is Future and Emerging Technologies (FET). The FET call finances visionary research projects targeting scientific breakthroughs and the development and application of radically new technologies. The estimated FET final budget will total nearly €3 billion.

3. The development of quantum technologies is part of the FET effort. In particular, a FET Flagship on quantum technologies has been approved in 2016 by the European Commission and will start in 2018. Allocated funds sum up to €1 billion.

4. Another major goal of the FET initiative is the development of high-performing computers. This investigation line targets a power increase in modern supercomputers of three orders of magnitude (from 10^{15} to 10^{18} floating point operations per second). The upgrade from the peta- to the exascale will provide unprecedented computational resources in practically all scientific fields.

Part II

Analysis and results

Appendix A

List of FET projects

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Acronym	Start date	End date	Total fund	EU fund	Website	Twitter	Facebook
A-LEAF	01/01/2017	31/12/2020	7 980 861	7 980 861	a-leaf.eu	@aleaf_h2020	aleaf.h2020
AQuS	01/01/2015	31/12/2017	2 000 500	2 000 500	kip.uni-heidelberg.de/aqus		
CHROMAVISION	01/06/2015	31/05/2019	3 567 025	3 567 025	chromavision.eu		
DEEP-EST	01/07/2017	30/06/2020	15 873 341	14 998 342	deep-projects.eu	@DEEPprojects	
DREAM	01/01/2015	31/12/2018	2 784 240	2 730 241	robotsthatdream.eu	@robotsthatdream	
ExaNoDe	01/10/2015	30/09/2018	8 629 247	8 629 247	exanode.eu	@ExanodeProject	Exanode-1669383456699997
ExCAPE	01/09/2015	31/08/2018	3 910 140	3 910 140	excape-h2020.eu		
EXDCI	01/09/2015	28/02/2018	2 551 875	2 551 875	exdci.eu	@exdci_eu	
GRACeFUL	01/02/2015	31/01/2018	2 404 943	2 404 943	graceful-project.eu	@gracefulproject	
MAGENTA	01/01/2017	31/12/2020	4 999 778	4 999 777	magenta-h2020.eu		
MAGicSky	01/09/2015	31/08/2018	3 396 439	3 396 439	magicsky-fet.eu	@magicskyf	
Microflusa	01/09/2015	31/08/2019	3 027 637	3 027 637	microflusa-project.eu		
NanoSmell	01/09/2015	31/08/2019	3 979 069	3 979 069	nanosmell.org		
nuClock	01/06/2015	31/05/2019	3 970 327	3 970 327	nuclock.eu		nuclock.eu
QCUMbER	01/09/2015	31/08/2018	3 219 721	3 219 721	qcumber.eu		
QUIC	01/03/2015	28/02/2019	2 774 375	2 386 875	quic-project.eu		
RYSQ	01/03/2015	28/02/2018	4 695 000	4 383 000	qurope.eu/projects/rysq		
SENSE	01/09/2016	31/08/2019	886 500	886 500	sense-pro.org	@senselowlight	
subCULTron	01/04/2015	31/03/2019	3 987 650	3 987 650	subcultron.eu	@subCULTron	
2D-INK	01/01/2016	31/12/2018	2 962 661	2 962 661	2d-ink.eu	@2D_INK	2D-INK-1419976004971237
WhiteRabbit	**01/04/2017**	**31/07/2018**	**99 750**	**99 750**			

Appendix B

Specific lists of FET projects

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