Science Ecosystem 2.0: how will change occur?

Thomas Crouzier
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Unit A6 – Science Policy, foresight and data

Contact: Emanuele Barbarossa, Katarzyna Bitka

E-mail: emanuele.barbarossa@ec.europa.eu

katarzyna.bitka@ec.europa.eu

RTD-RISE@ec.europa.eu

RTD-PUBLICATIONS@ec.europa.eu

European Commission
B-1049 Brussels

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ABSTRACT

The report analyses the potential impact of a transition towards Open Science on the stakeholders of the research ecosystem. The following findings are discussed.

- Innovative digital tools that facilitate communication, collaboration, and the data analysis will enable Open Science practices.
- All stakeholders of the research ecosystem will benefit from Open Science, although it will change work habits and business models.
- Digital platforms will facilitate innovation by streamlining all phases of the innovation process, from the generation of ideas to experimental work and fundraising.
- Citizens will become new players of the research ecosystem. They will shape science policies and contribute to scientific research through citizen science actions and by funding researchers.
- Digital science start-ups will shape the future of Open Science and innovate in the exploitation of the flow of information made publicly available with the advent of Open Science.
- The EU can accelerate the transition towards Open Science thanks to its unique position as funder and policy maker. A three-step program is suggested that will: 1) support the on-going transformation; 2) make systemic change to open the way to fully implemented Open Science; and 3) unlock the societal and economic value of Open Science.

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EXECUTIVE SUMMARY

Purpose and motivation. Since the scientific revolution of the 16th and 17th century, humanity has pursued a fantastic scientific endeavour that now relies on millions of researchers spread throughout the world, building on each other's discoveries and mistakes to advance knowledge and technology. An unbiased, instantaneous, and unhindered flow of information between these individuals would allow all research projects to be perfectly complementary. However, human and technological barriers have been hindering free communication and slowing down progress. Today, the technological barriers to a more open and interconnected research ecosystem seem to be breaking down, driven by new communication technologies, progress in computing and algorithms, and the advent of data-driven research.

As scientific research becomes a more open endeavour, all stakeholders of the research ecosystem must redefine their role and their approach to science. Researchers will have to adapt to new possibilities, to new tools, and to new responsibilities. The innovation ecosystem will also change by embracing more openness and being more inclusive. Funders, academic institutions, and policy makers will need to fund, inform, and legislate to accelerate the transition.

Supporting the transition towards Open Science is indeed essential since several barriers other than technological remain intact. In particular, the uncertain effects of such large-scale overhaul of the research and innovation ecosystems discourage key stakeholders such as researchers and policy makers from investing in Open Science. A clear vision of the impact Open Science will have on all stakeholders and of the path to the successful transition is key. This report, organised in four distinct chapters, will provide such a vision.

- Chapter I: Introduction
- Chapter II: How will the transition to Open Science affect the different stakeholders of the science ecosystem and the interactions between them?
- Chapter III: What are the conditions for the success of Open Science?
- Chapter IV: Scenarios and policy options.

Approach to the study. This report is the result of the personal experience and knowledge of the author as an academic researcher engaged in Open Science. He gained his insight into Open Science questions by engaging with key stakeholders of Open Science communities including librarians, entrepreneurs, policy makers, Open Science activists, and academics researchers. The author is particularly interested in the recent development of digital tools for researchers that are enabling Open Science.

This report focuses on the impact such tools will have on each stakeholders of the research ecosystem and how they will facilitate the transition towards Open Science.

Findings. The report provides a series of examples of how Open Science digital tools are affecting stakeholders of the research ecosystem. The potential for these tools to facilitate communication, collaboration, and the analysis of open data is highlighted. The development of innovative digital tools for researchers is deemed essential for the transition towards Open Science.

Although some stakeholders, such as scholarly publishers, will have to adapt their business models, Open Science will be clearly beneficial for all stakeholders of the research ecosystem once fully implemented. Increased communication and collaboration will lead to more interaction between the stakeholders.

Open Science will have profound effects on the innovation process. Digital platforms will facilitate innovation by streamlining all phases of the innovation process, from the generation of ideas, to experimental work and fundraising. This will favour the transition towards open innovation and user-based innovation models.

Open Science will increase public involvement in research and science. Citizens will be better informed, and will be directly engaged by participation in studies, sharing of ideas, and helping fund certain research projects. Citizens will become new players of the research ecosystem.

Digital Science companies will define the future of Open Science. They are key enablers of the transition towards Open Science. They need to provide researchers with user-friendly and rewarding experiences to drive their adoption of open Science practices.

Recommendations. The European Commission (EC) can help with this transition thanks to its unique position as funder and policy maker. A three-step program is suggested:

- Enabling the transition towards Open Science by:
  - Requiring open access for published articles and data.
  - Funding open access.
  - Supporting Open Science practices.
  - Building a sustainable Open Science infrastructure.
  - Stimulating the nascent European digital science industry.
  - Informing and training.

- Opening the way to fully implemented Open Science by:
  - Providing field-specific guidelines for opening all aspects of the research lifecycle.
  - Adopting standards for recognition of authorship and metrics of impact of data published in non-traditional forms.
  - Encouraging and rewarding open peer-review of the published research outputs.
  - Encouraging private companies to embrace Open Science practices.

- Extracting value from Open Science by:
  - Connecting companies and NGOs with the researchers and research results.
  - Creating a European space for knowledge and expertise.
  - Nourishing the digital science start-up ecosystem.

CHAPTER I - INTRODUCTION

Open Science practices are breaking barriers that prevent the free flow of knowledge produced by researchers. The adoption of such practices is bound to redefine the relationships between the stakeholders of the research ecosystem, and between researchers and society. Chapter II looks at the impact Open Science will have on stakeholders of the research ecosystem based on current trends. Chapter III identifies and describes the conditions for a successful transition towards Open Science. Finally, Chapter IV looks towards 2030 through a series of scenarios describing what a fully implemented Open Science ecosystem would look like. It also includes a set of policy actions that could make this vision a reality. This report is written with the experience and vision of a scientific researcher, and is illustrated by examples of new digital tools that are enabling these changes.

Science in transition. With the advent of scientific academies and their publications in the late seventeenth century, science made its first step towards the more rapid and unhindered communication of scientific discoveries. The creation of the Internet in the late twentieth century dramatically increased the speed at which the information was communicated. Although information travelled faster than before, research was neither conducted nor communicated differently. Letters were simply replaced by emails, and paper journals by PDF files. Only in the past ten years have new digital tools designed specifically for researchers accelerated the transition towards Open Science. These tools are most often developed by entrepreneurs that have identified major gaps in the research system that could be filled by digital technologies. Hundreds now exist that facilitate information sharing, allow publications to be peer reviewed by all, extract quantifiable information from publications using text mining, and intelligently recommend of reading material to the busy researchers.

We are witnessing the birth of the digital science industry. Social network platforms for researchers have already been successful at attracting millions of users, an impressive trend given the estimated 7 million scientific researchers currently active worldwide[1]. The recent success of several other initiatives such as AddGene[2] and ORCID is similarly impressive (Figure 1).

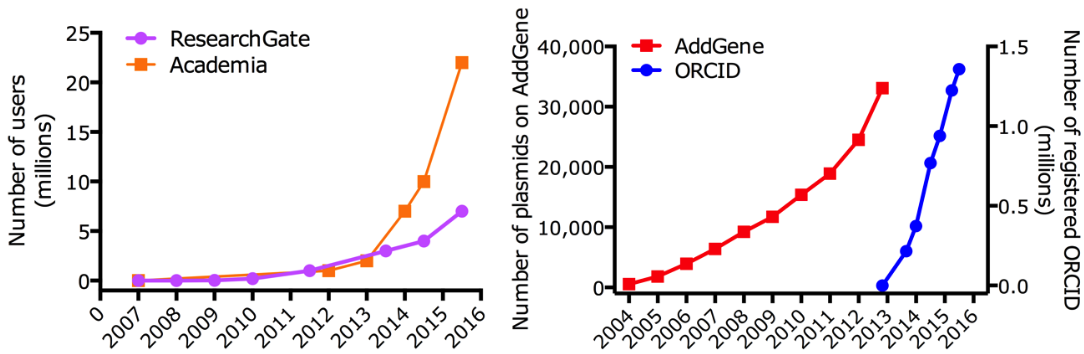

Figure 1. (A) The growth in the number of users of social network platforms for researchers (Researchgate[3] and Academia[4]). (B) The growth in activity of two Digital Science platforms, one that distributes plasmids to researchers (AddGene[2]), the other attributing unique identifiers to researchers (ORCID).

The development of digital tools for researchers go hand in hand with the recent progression of open access publishing and the increasing amount of data deposited in open repositories (Figure 2). For instance Open Access publishing is encouraged by social network platforms for researchers, since the articles can be directly linked to the researcher's profile. Open access publishers such as the Public Library of Science (PLoS) are also on the forefront of experimenting with alternative metrics of impact and peer review models.

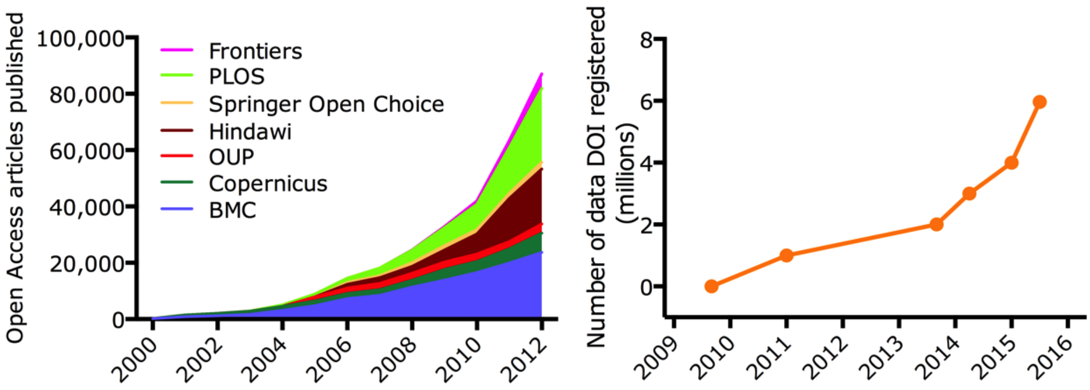

Figure 2. (A) Number of articles published by major open access publishers (figure adapted from[5]. (B) Number of Digital Object Identifiers (DOIs) attributed to datasets by the DataCite organization[6].

Still a long road ahead. The data shown here suggests that the transition towards Open Science has already started. It suggests that digital science tools are innovating, and that some tools are successfully attracting users. However, although this trend shows the potential of introducing new tools to researchers, it does not reflect the degree of awareness and the adoption rates of the most innovative tools such as social networks, collaborative writing tools or blogs for researchers. Recent reports from the Science 2.0 Leibniz Forschungsverbunds[7] and the Young European Associated Researchers (YEAR)[8] emphasise the lack of awareness of Open Science and Science 2.0 (Figure 3).

Unfortunately, the relative lack of awareness of researchers for Open Science practices is matched by other stakeholders of the research ecosystem. Without proper actions from leading stakeholders such as the European Commission (EC), it may take many decades before Open Science is truly implemented. The main barriers to change are described in Chapter III. However, part of the reason lies in the lack of a clear vision of how Open Science will impact research and society. This report is an effort to illustrate the outcomes of a successful transition towards Open Science.

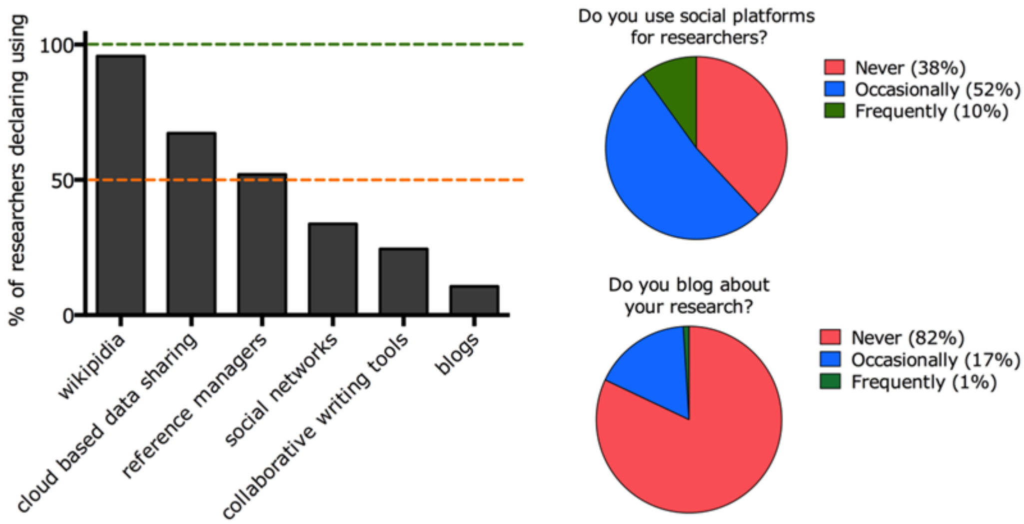

Figure 3. (A) Adoption rate of digital tools by researchers (figure adapted from[7]). (B) Adoption of social platforms and (C) blogging by young European researchers (figure adapted from[8]).

CHAPTER II – HOW WILL THE TRANSITION TO OPEN SCIENCE AFFECT THE DIFFERENT STAKEHOLDERS OF THE SCIENCE ECOSYSTEM AND THE INTERACTIONS BETWEEN THEM?

In this chapter, we will describe how Open Science will impact the science ecosystem and change the dynamics between its stakeholders. We will review the current trends in Open Science and speculate on the impact of a transition to Open Science.

2.1. How will Open Science impact researchers?

Researchers are key players of the research ecosystem, and as such will be instrumental in the transition towards Open Science. A number of Open Science tools specifically targeting researchers are already available. They provide a glimpse at the impact Open Science might have on research and researchers in the next 20 years. In this report, we provide a list of current tools (List 1 to 23) and speculate on their evolution over the next 5 years.

The researcher's workflow. Better access to research results and the ever-increasing number of digital tools for researchers are impacting every stage of the research cycle, from project conception to the publication and discussion of results. The conception of research projects is facilitated by innovative search engines (List 1) and reference manager tools (List 2) that suggest relevant articles to read by analysing the user's search history and collection of saved publications. Soon, these tools will analyse the researcher's interests in more depth by text mining the content of published articles and laboratory notebooks. They will establish links between articles, authors, institutions, funders, equipment, and protocols to help researchers navigate the millions of files (articles, figures, datasets) published every year. It will become easier to discover literature relevant to one's research interest, but also to quickly identify the most important papers of unfamiliar fields.

The format in which research results are published has also started to evolve (List 3). Articles will continue to be richer and more connected to other relevant documents and datasets. Videos, interactive graphs, and the code and executable versions of software will commonly be directly embedded in the text. Numerous links to related information on authors, reagents, and protocols will provide the reader with all the information necessary to reproduce the experiments.

The development of text mining technologies will profoundly impact the daily tasks of researchers. In addition to reading papers, researchers will rely on complex algorithms to extract and summarise valuable information from published articles and data. By analysing several articles dealing with similar subjects, these tools will be able to form links between publications and extract new information such as constants and facts. For instance, the mass of a single human cell has been measured by various techniques. Text mining algorithms could extract the values published by the different groups and provide an average number with statistical certainty. But such tools could also point out potential binding partners of cell signalling molecules, or estimate what the best material for bone defect repair could be.

Digital lab notebooks are replacing traditional paper notebooks and in the process changing the way experiments are executed and recorded (List 4). They are mobile, and support rich text, videos, and images. The research data is stored digitally, which makes it easily sharable and searchable. Protocols and workflow repositories (List 5) are directly integrated in lab notebooks and can be easily shared to improve the reproducibility of research. Electronic lab notebooks will evolve to include many of the tools discussed below. For instance, they will communicate with instrumentations to directly store recorded data and offer a space to write and publish manuscripts. They will transform into platforms that support the researcher from the planning stage to the communication of results. Computer code will be written using online collaborative platforms such as the IPhython notebook[9] that combines code editing with code execution, rich text, and media such as mathematical formulas and plots (List 6).

Precious research tools, such as plasmids, tissues, cells, and materials, are also increasingly being openly described and shared through online platforms (List 7). As these develop, it will become more common for academic laboratories to take the role of suppliers of advanced reagents. Unique identifiers will be attributed to each sample to help cite them and give credit to the sample producers, similar to digital object identifiers (DOIs) used for digital files.

The analysis of the data generated will also become more collaborative through online platforms. Already certain platforms allow researchers to work together on bio-informatic analyses, statistical calculations, and the generation of plots and graphs (List 8). Such tools facilitate the analysis of data that can come from research groups scattered throughout the world by centralizing the analysis, providing standards, and providing tools to immediately discuss and share the results.

Networking. Several tools facilitate collaboration by allowing researchers to share information and discuss research projects, protocols, experimental results, and data analysis (List 9 and 10). Other platforms have specialised in connecting researchers with potential collaborators by displaying detailed profiles of their users. These tools will evolve to better understand the research interests of its users and suggest new collaborations based on complementary expertise or geographical localisation. These tools will also become more inclusive by inviting other stakeholders from the research ecosystem to connect with researchers including the private sector, funders, and public agencies.

Open Science will also encourage the subcontracting of experiments to other academic research groups or private companies. Science Exchange[10] already uses an online platform to help academic and private research facilities to open their equipment and expertise through an online platform. Other startups are developing automatised experimentations using robotics. These service providers will offer highly reproducible and high throughput experimentations for a fraction of the current cost (List 11). If managed properly, this push for more subcontracting in academic research will allow students and researchers to focus on more creative tasks and experimentations, leaving fastidious screenings to robots.

Publishing. Open Science will make a strong impact on the way researchers communicate their research results. Open Science practices will encourage researchers to publish their results using paper repositories (List 12) or open access platforms (List 13). Early versions of these platforms exist today, however these will likely evolve to include the different steps involved in publishing scholarly articles. For instance, the generalisation of collaborative writing tools will accelerate the writing and editing process, allowing several users to work on documents simultaneously (List 14). Writing and publishing will become increasingly intertwined, with certain collaborative platforms such as Overleaf[11] already offering to directly submit manuscripts to open access journals. In the near future, collaborative writing tools will also include quality control features through peer review, commenting and rating. Once scientifically validated, researchers will be able to directly send their manuscripts to journals, repositories, blogs or their future-equivalent. Unique author identification services will clarify authorship (List 15), and digital object identifiers will allow the articles to be tracked as it is being shared and cited.

The peer review system will change to account for these new forms of instantaneous publishing. Open peer review invites all researchers to comment on published documents and rate them (List 16). In addition, scholarly journals will progressively adopt a more open form of peer review, where anonymity will no longer be the norm and reviewers will be credited for their contributions. The Public library of Science (PLoS) along with PeerJ and others, are encouraging their reviewers to provide their names and allow the review history to be published alongside the article. In addition to a more transparent peer review process, appropriately recognising the time and effort typically invested by researchers in peer review could improve the quality control of academic research. Based on this assumption, Publon[12] provides researchers with public records of their reviews, while Rubriq[13] financially compensate reviewers for their work. The impact of Open Science on the peer review system will have repercussions beyond the academic publishing system. As the peer review process becomes more open and transparent, trust of researchers and the general public in the scientific publishing system will increase, and scientific fraud will be discouraged.

Outreach. Open Science also means that the latest scientific knowledge should be available to all citizens. New services help researchers communicate their research to non-researchers by publishing lay summaries, designing graphic representations of research results, or helping the traditional media better understand the latest discoveries (List 17). Citizens also have the opportunity to participate in research through citizen science platforms (List 18). On sites such as Scistarter[14] and Zoonivers[15], anyone with an Internet connection can help survey the moon's crater, or report water levels of their local stream to help predict flooding. These new partnerships between society and researchers will broaden significantly with the transition towards Open Science.

Although many do not realise it, there is a thirst for science outreach from both the researchers and the public side. Good illustrations of this untapped potential are the recent "Thesis in 180 seconds" events, that were created in Australia in 2008 and that are now organized in Canada, France, Belgium, and Morocco amongst other countries. The French 2015 version gathered nearly 700 PhD students and the final attracted over 840 spectators that came to hear about cutting edge research conducted by PhD students, explained in lay terms[16].

As researchers connect more closely with society, more platforms will allow them to directly speak to citizens through more frequent appearances in traditional media and online platforms such as Ask a Scientist[17] or Ask an Engineer[18]. Researchers will offer their point of view and their expertise on matters that interest the general public. A stronger involvement of researchers in civil society will contribute to change the *ivory tower* image of academic research, and will positively affect the academic culture and work ethics of researchers.

Research evaluation. Open Science will impact the definition of a successful researcher, through the development of new metrics of research impact (List 19). These will come as an alternative to the impact factor of journals and citation counts that provide an incomplete picture of the scientific, societal, political, and economical impact research results can have. Alternative metrics (also called altmetrics) will trace published research outputs, whatever the form, and analyse the complementary information associated with published results (i.e. metadata) to assess its impact. Once mature, the adoption of these new metrics by employers and funders will become a strong incentive for researchers to make wider use of online platforms to publicly connect, collaborate, and expose their work.

Current altmetrics assess the short-term impact of the work by tracking how publications spread through online communities such as social networking platforms and blogs, and how they are relayed by the traditional media. Beyond citation counts, the longer-term importance of the work will be linked to the re-use of the information in grant proposals, policy proposals, reports, blog posts, patents, and presentations. Accurately detecting and quantifying the frequency at which research results are mentioned in such a variety of documents will be challenging. But even more challenging will be to detect the context and possible impact of the mentions.

Future metric systems will be more quantitative and make in even deeper analysis of the impact of scientific publications. For instance, these tools will be able to trace the impact of a work beyond its first degree of citation. If work 1 enabled work 2, which then enabled work 3, then work 1 could be recognized for work 3 to some extent. Advanced systems could also help uncover hidden citations when a review is cited instead of the original work. They could also provide a more integrated view of a researcher’s career. If a researcher has produced five poorly cited papers, but all were cited repeatedly and positively in a ground-breaking work, then the researcher’s contribution to the innovative work will be highlighted. Finally, new research evaluation tools will have to be developed with new citation tools. Although the accurate detection of citations and their context will make progress, it will be made easier with authors providing more information about their references while writing. These new citation tools will work on all publication forms and will break away from the current citation system with limited number of references, a heritage of paper-based publication. The choice of citations will loose its randomness, providing more systematic ways to give credit for work that is built upon.

Fundraising. Fundraising is one of the main activities of researchers. In addition to writing the proposal, time is spent on looking for grants and understanding their requirements, such as the proposal’s structure, the deadline, the scope, and the funding conditions. Digital tools help researchers streamline the process by identifying grants from public agencies and the private sector (List 20). Although grant search engines already exist, these will become more advanced by personalising the search results to the research competences and grant-application history of the applicant. They will provide statistics of success based on the profile of the applicant and suggest a maximum number of hours the researcher should spend on a given grant application given the other opportunities available.

More open communication between researchers and the public will lead to the development of science crowdfunding (List 21). In the United States, philanthropic donations rose to $335 billion last year[19], and up to €150 billion in Europe[20]. Science only attracts a small fraction of these donations. However, there is no inherent reason for that. Private philanthropy can be driven towards research through a better understanding of the concrete impact of research, and by the involvement of more researchers in civil society. Crowdfunding will then become a major funding source of scientific research in the next 20 years.

2.2. How will Open Science impact research organisations?

Libraries. Open Science will have a direct impact on researchers but will also profoundly impact universities and research institutions. For university libraries, the development of open access repositories (List 22) will increase several fold the amount of freely available scholarly information, largely enriching their offering of content to students and researchers. However, with these opportunities come challenges. University libraries will be at the forefront of the transition towards Open Science and will have to solve technical challenges to make this massive amount of information easily exploitable and accessible to their users. With more open and data intensive research, libraries also face the daunting task of managing the massive amount of data that researchers will generate. Research organisations will progressively adopt more standardised solutions for data sharing by using existing data repositories or by following a set of international standards. Research organizations will also need to select a set of tools and provide training for their researchers to help standardise Open Science practices, at least within organizations.

Although Open Science will open access to research results and lower or eliminate journal subscription costs, the transition period could be costly for academic institutions and funders. Many scholarly journals have adopted a "hybrid model", where most articles are behind a paywall, but can be made accessible to all for a fee. Research organisations then pay the subscription to the journal, while authors pay to publish in open access. This *double dipping* raises the cost of knowledge dissemination, rather than lowering it. Subscription costs need to be adjusted by publishers to take into account the share of open access articles that have already been paid for. Most publishers declare adjusting their subscription costs in such ways; however the cost/benefit of paying for open access in a hybrid journal is complicated to assess with the frequent changes in public policies and prices.

Technology transfer offices. Opening science also means new challenges for technology transfer for the industrial liaison offices of research organisations. These offices will need to inform researchers about the extent to which they can share information, without compromising patent applications or non-disclosure agreements. They will help arrange an increasing number of collaborations between the researchers and the private sector, making sure that win-win situations are the norm. Although digital tools will help connect researchers to other stakeholders of the research ecosystem, larger universities will develop their own tools to remain at the interface between its researchers and external collaborators. Already universities such as MIT and Caltech embrace this trend by connecting industrial partners to researchers[21] and patents[22] through online searchable databases.

With the digitalisation of research activities, research organisations will be able to use that information to make more informed strategic decisions. To this day, most research organisations only have a poor insight into what research is being carried out within their departments. Tools that gather information about published and unpublished data within the organisation could create new synergies by suggesting collaborations, helping compose research centres, and by helping undergraduate and graduate students find the right research groups for internships[23]. Stockholm University (SU) in Sweden is a good illustration of the institutional use of such tools. SU has launched a pilot program to allow researchers to store and share their data using the FigShare's data repository services. Although several SU institutes had their own repositories, the goal is to provide all SU researchers with equal opportunities to archive and share their data. Such turnkey solutions for data archiving will become increasingly valuable as research funders reinforce their requirements regarding data management plans. The data generated by users will inform SU leadership on research activities within their institutions. However, it seems too early to know how these new insights will affect SU's internal research policies.

Institutional leadership. With Open Science, the activities and performance of research organisations will be more exposed than ever. The new forms of smart metrics that will allow research results and researchers to be evaluated in an Open Science environment will undoubtedly be used to also evaluate universities and research centres. Tools such as Elsevier's SciVal application suite are already allowing research organisations to evaluate their own research activity landscape base on bibliometric data. Innovative alternative metrics tools (List 19) are also starting to be used by research institutions. The Research Strategy Office of the University of Cambridge helps with reporting to institution funders such as the Wellcome Trust and the Research Councils UK. They recently reported having experimented with altmetric tools[24] to provide a more detailed view of the attention received by the University's research output. The office was able to uncover over 400 mentions of the University's research papers in policy documents. Used as a complement to current metrics such as impact factors and number of publications, altmetrics will become essential to showcase through concrete data the direct and indirect impact of a research organisation's output.

As a result, research organisations will become more proactive in managing their research impact. They will be more informed about on-going research programs, will promote press coverage of discoveries, and will actively help researchers obtain funding through public, private, and citizen sources. Some universities, mostly from the United States, are already very active in these respects. The Massachusetts Institute of Technology, for instance, has made a reality TV show from a chemistry laboratory class[25]. By doing so, it has reinforced its image as a high-tech university, demonstrating innovation in education, and providing an insight into the science and education one gets at the university.

2.3. How will Open Science impact the public sector?

Research funders. The mission of public funders is well aligned with the principles of Open Science, since the research results benefit all members of society, and the social and economic return on investment is maximised. However, funding agencies will also become more effective by using digital tools that analyse published results and their metadata to provide a global image of the research funding landscape. Tools such as Uberresearch[26] highlight underfunded questions and indicate where the funding would provide the most results per euro spent. In the near future, with progress in text mining and semantic processing, such decision support systems will become increasingly reliable when estimating the outcomes of research projects.

Government. Open Science will facilitate data-driven policy decisions by governments. This will largely be due to researchers using lay summaries to better communicate the importance of their work to all members of society, and especially to politicians. In addition, along with more science-informed citizens will come a push for more science-friendly policies and initiatives. Investment in scientific research is beneficial for society in the mid- to long-term but provides little immediate returns. Open Science will bring more short-term and very concrete return on investments in the form of headlines in the news about the latest discovery, the launch of a new start-up, or a graphic summary of a PhD student’s thesis that goes viral on the Internet. Investments in research will then be more easily justifiable by politicians.

Public health organisations. The impact of data sharing or lack there-of has been well illustrated in the recent Ebola outbreak in Western Africa. Predictive signs of a risk of an Ebola epidemic were published in the late 1980s, long before the Ebola outbreak[27]. However, the studies did not involve local collaborators and were published behind paywalls that made it financially inaccessible to Western African researchers. Thus the information did not reach the public authorities, who did not prepare for such an event. Open Science will help the public sector by more directly involving the population concerned by the studies and by allowing researchers and other professionals to access the latest information.

During the outbreak, Open Science practices were a precious ally in the fight against the epidemic. Genomic analyses of the virus were openly shared by researchers, allowing new collaborations to quickly build on raw data[28]. Geneticists and evolutionary virologists came together to confirm the origin and the transmission mode of the virus. They estimated routes of infection and predicted the rates of mutations of the virus. This information was important in the management of the crisis by local and international public health organisations. For instance, it showed where to concentrate relief efforts and what practical advice to give on the ground to limit the spread of Ebola. But it was also important for drug and vaccine development laboratories and pharmaceutical companies to more quickly design new therapies, diagnostics kits, and vaccines.

2.4. How will Open Science impact the business sector?

Public investment in R&D in combination with the private investment it stimulates creates economic value that largely surpasses the initial investment. Increasing the accessibility of research results would increase the impact of the investments and would create more opportunities for value to be created.

Small and medium size enterprises (SMEs). The cost of subscriptions to journals is often prohibitive for SEMs, limiting their access to the scientific literature (Figure 4). A Danish study of 98 SMEs revealed that the use of open access material is common amongst private companies, with 72% of researchers using free repositories (List 22) and 56% using open access journals monthly or even more regularly[29].

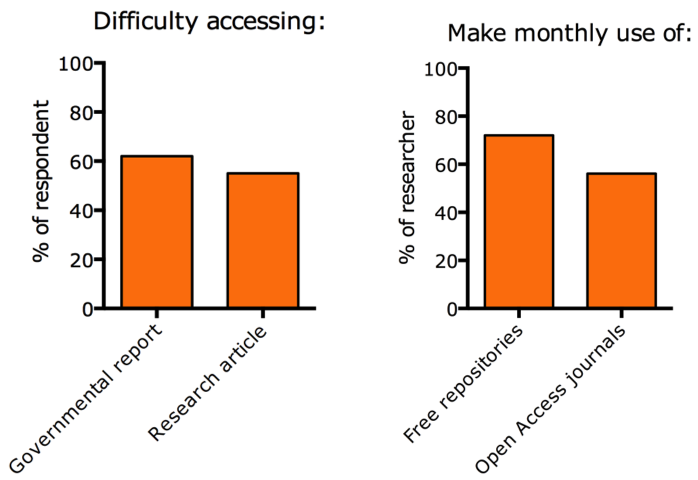

Figure 4. Small and medium size enterprises (SMEs) and open access. SMEs have difficulties accessing scholarly literature. However, they already make widespread use of open access articles. Data extracted from a study by Houghton et al.[29].

The study also describes the importance of open access in the business development of SMEs. The survey suggests that without open access, 27% of products and 19% of processes developed over a three-year period would have been delayed or abandoned. In addition to a lack of access to scientific literature, a cultural barrier also prevents companies from thinking about looking for solutions in academic research[30]. A more Open Science will be more inclusive of private companies, and will raise awareness of the availability of freely accessible research results.

Large companies. Open Science practices and tools are also being adopted by larger companies. This is especially true in the pharmaceutical and biotechnology sectors that are increasingly outsourcing their innovation process. Sanofi, for instance, has recently developed an internal collaboration tool to connect all 13,000 employees of the group's R&D activities. With the recent acquisition of Merial and Genzyme, Sanofi also acquired new expertise and technologies scattered throughout the world. The platform provides searchable profiles of all R&D employees, and allows them to share and discuss their research activities, data, and documents. Due to intellectual property concerns, the platform is for internal use only. However, specific projects can be opened to external collaborators, perhaps the start of a broader adoption of Open Science practices. Several other large European companies have launched similar platforms, including Michelin, Ernst and Young, Pfizer, and Lafarge.

In addition to collaboration tools for internal use, social networks for researchers such as Academia[4] or Researchgate[3] can also be an effective way for companies to connect with research communities (List 9). Already, social networks for researchers are using the information generated by their users to target job advertisements to the right talent pool, making hiring qualified researchers quicker and cheaper. These will increasingly be used by companies to follow the career of promising young researchers, providing them with a range of opportunities such as internships, fellowships, or employment.

Over the past few years a number of large companies have been showing the way towards more open research and innovation. For instance, GlaxoSmithKline (GSK), a British multinational pharmaceutical company, has open result summaries of over 6,000 clinical trials since 2004[31]. They have also created an open research centre at Tres Cantos (Spain) where researchers are invited to conduct their research with the technical and financial support of GSK[32]. In association with the Medical Research Council and UK academia, GSK has also recently launched an open innovation research initiative to improve our understanding of inflammatory diseases. Another example of a successful open innovation strategy comes from the Tesla automobile company. Tesla established R&D partnerships with major companies such as Panasonic and Toyota to develop and assemble their first model[33]. They now continue to show openness by releasing the rights to over 200 of their patents. Their goal is to attract investment in the electric vehicle industry, which would help grow the market size.

2.5. How will Open Science impact the innovation system as a whole?

There are strong similarities between the Open Source movement of the 1990s and 2000s and today's transition towards Open Science. The advent of Open Source has been a strong driver for innovation and economic growth[34]. Open access to software source code, combined with online tools such as GitHub[35], formed communities of coders that worked collaboratively to build innovative and complex software. Even beyond the software industry, the Open Source movement has been a driver for innovation by providing a training ground for young coders who could easily share their accomplishments and receive feedback from companies and coding communities. Similarly, opening access to research will allow research results to be reused by scientists and by educators, and will facilitate access of scientific data by all citizens. Scientific projects will become more collaborative, enabling more complex problems to be solved by ambitious and innovative solutions. A closer proximity between the general public and scientific research will help demystify it and will encourage more citizens to engage and understand scientific research. This will set good grounds for more and better-trained innovators with fresh perspectives.

New forms of innovation models such as Open Innovation (or Distributed Innovation) rely heavily on efficient access to information and communication. Hence, Open Science and its associated digital tools will facilitate Open Innovation by, 1) allowing ideas to emerge from more stakeholders, 2) by creating new partnerships, and 3) by providing digital collaborative platforms.

Allowing ideas to emerge from more stakeholders. Open Science will engage with civil society by being more accessible, comprehensible, and by welcoming more input from non-researchers. Digital tools will provide close interactions between citizens, professionals, and research groups. Through digital platforms, citizens will be able to comment on research projects, make suggestions, and make donations to support the research activities. Already crowdfunding sites allow citizens to fund research that interests them (List 21). Experiment.com[36] for instance, has distributed nearly 2 million dollars since its launch in 2012 (Figure 5). Citizen science platforms encourage everyone to share their time and expertise to help solve challenges (List 18). The diversity of origin, education, and point of view of the problem-solvers engaged through these platforms work in favour of innovation. Hence citizens and professionals, now largely excluded from the innovation system, will soon become one of its essential actors.

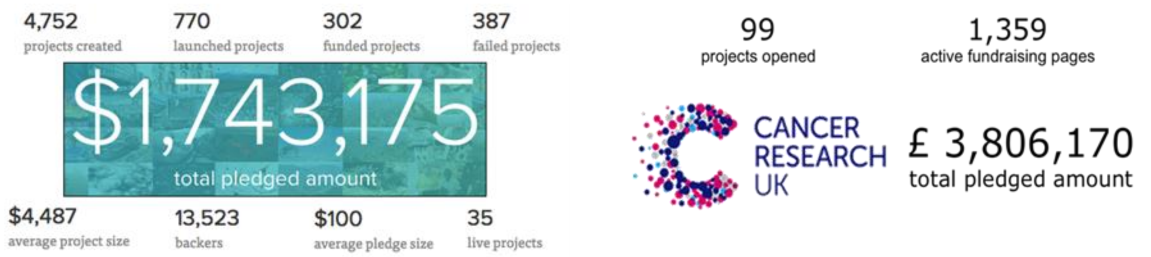

Figure 5. Activity report from the Experiment.com[36] and the Myprojects[37] websites, two of the largest crowdfunding platforms for research projects. The amounts and numbers are cumulative since the launch of Experiment.com and Myprojects in 2012 and 2009, respectively.

Creating new partnerships. More open scientific research will also imply better visibility for the researcher's activities, which could lead to more partnerships. Several platforms already allow researchers to display personal profiles, which can include research interests, domain of expertise, and list of inventions (List 9). Such online platforms will evolve to automatically build a full picture of the research activity by analysing all published research results, including lab notebooks, reports, and raw data. All stakeholders of the innovation ecosystem will then be informed of the latest advances made by the specific laboratory. These tools will fluidify the innovation process, providing opportunities for researchers to develop their ideas into inventions, for companies to solve problems using the creativity of academic research, and for investors to identify promising new technologies. On other platforms, private companies and NGOs will seek the assistance of citizens and researchers to solve some of their most pressing challenges. Already today, on Kaggle[38] and Innocentive[39] and other similar platforms (List 23) companies ask communities of professional and amateur scientists to develop innovative solutions to their problems.

Providing digital collaborative platforms. All stakeholders of the open innovation ecosystem will be interconnected through digital collaborative platforms. These platforms will be the result of the combination of lab management tools, electronic lab notebooks, collaborative writing tools, and virtual meeting tools that currently exist. Research groups in academia and their industrial partners will use them to work on common projects, communicate experimental results, share files (articles, data, presentations), organize experimental plans, and meet virtually. With the innovation process shifting towards more openness, more stakeholders from the innovation system will be included. For instance, funders, regulatory agencies, the media, and other professionals will be able to access the platform and provide real time feedback and expertise at all stages of the innovation process.

2.6. How will Open Science affect the interactions between academia, the business sector, and the public sector?

Open Science and Open Innovation will connect academia, the business sector, and the public sector. A number of tools are already available to connect the private sector with academic researchers (List 9). Although organisations have unique final objective, they all play key roles in scientific progress and the development of our societies. Opening data and communication between all stakeholders of the research ecosystem will tighten their interdependence. Daily interactions between business and academic researchers or between regulatory agencies and universities will push these organisations to relocate closer to each other. Companies have already started to cluster around major research centres. One can imagine that regulatory agencies will also open offices within research centres.

The increasing number of interactions between the stakeholders of the research ecosystem through online platforms will generate valuable information if properly gathered and analysed. A start-up named Symplur[40] already analyses communications between all stakeholders of the healthcare industry on social media, including business, public agencies and academic researchers. The result is access to real-time news and trending topics in the healthcare industry.

CHAPTER III – WHAT ARE THE CONDITIONS FOR THE SUCCESS OF OPEN SCIENCE?

This chapter identifies the factors necessary for a full and successful implementation of Open Science in Europe. First, we will identify the current driving forces of Open Science, and point out how these can be reinforced. Then, we will assess the current and future obstacles restraining Open Science, and suggest how these can be overcome.

3.1. Drivers of Open Science

The transition towards Open Science is currently driven by numerous human and economic factors that could be reinforced and sustained to ensure its successful implementation.

Mature digital tools. Open Science is driven by a growing collection of digital tools that help produce, analyse, use, and share data produced by researchers (Chapter II and List 1 to 23). Most of these tools use cloud technologies that allow the software to be run on remote servers. This model is advantageous since it requires no installation, is compatible with various operating systems, and can be run on mobile devices. The development of high-quality tools and their progressive adoption by research institutions as standards are main drivers of the transition towards Open Science.

This trend can be sustained by supporting the nascent digital science industry that produces the innovative digital tools that drive the transition towards Open Science. In parallel, the stakeholders of the research and innovation ecosystem should also be introduced to these tools to increase adoption rates.

The increasing complexity, interdisciplinarity, and reliance on data of research projects. Scientific research is an endless race towards ever more complex questions and challenges. Today's typical research project requires expensive equipment, and the conjunction of a multitude of expertise. This is illustrated by the increase in the number of individual authors per paper and of proportion of academic publications that involves international collaboration both in the United States and in the European Research Area (Figure 6).

With the scientific enterprise becoming more collaborative, researchers naturally adopt more collaborative and communicative habits. For instance large ERC-funded projects require a website which details the scope and impact of the research. Large consortiums also often use research project management platforms such as AdminProject[43] or the European Commission-funded OpenAIRE platform[44] to create common digital space to share research data and documents, manage the project, and discuss results. These are seeding habits of data-sharing and open communication that could then translate into more systematic Open Science habits. Thus, large collaborative projects, many funded by the ERC, are driving the adoption of Open Science practices.

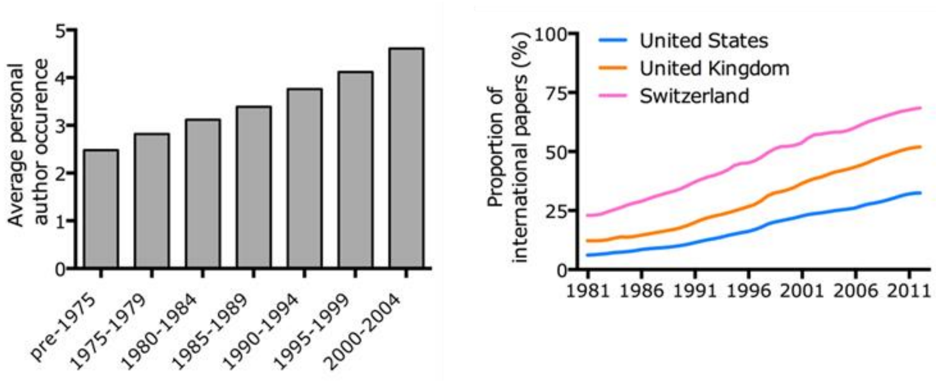

Figure 6. (A) The average number of authors per publication referenced by the Pubmed database has increased two fold since the late 70s[41]. (B) In the meantime, research has become much more internationally collaborative[42].

In addition, research data can be recorded and analysed more rapidly than ever thanks to new technologies and methodologies. The inflation in the amount of data produced is shifting the value away from the data itself and towards its analysis. Data is thus becoming more of a commodity that many researchers will share willingly. This is an opportunity for Open Science. As new generations of data scientists are trained, they must be accustomed to openness in research. They must also be trained to play key roles in developing the tools that will exploit the information made available by Open Science.

Public exposure and career advancement. Social networking sites for scientists, post-publishing peer-review sites, or altmetric services are also a way for academic researchers to showcase their achievements and their professional abilities. These services allow researchers to build an online presence that will become increasingly important when assessing a researcher's activities. In a context of increasing competition in academic research, these tools are effective ways for researchers to stand out and increase their chance of career advancement. Several digital platforms for researchers such as Researchgate[3], Publon[12], and ORCID[45] use this argument to encourage researchers to participate. The personal benefits of such practices will continue to be a major driver in the transition towards Open Science and can be reinforced by the official recognition of these tools in the evaluation process of researchers.

Research organisations will also invest in Open Science as part of their public relations strategy. Their public commitment to promote Open Science could improve their public image in the short term. But it also constitutes a good long-term strategy, since their online visibility will increase with the better accessibility of the data which cite them as host institution. Research organisations will also shape their public image by being more communicative about the research breakthroughs that are being made within their organisations. And because Open Science will allow independent organisations to review in more detail the research outputs of universities and research centres, research organisations will monitor more closely the research outputs and educational resources published by their employees to better control the outcomes of the evaluation.

Open Science-friendly policies. Open Science has become an essential part of modern science policies. Governmental policies are needed to help accelerate change in such complex systems. Funders and national research institutions have already proven to be strong drivers of change. For instance, the United State's National Institute of Health (NIH) has proven that rapid transitions toward open access can be achieved if it is required from an influential funder[46]. The proportion of freely accessible articles funded by the NIH rose constantly since the introduction of the policy, reaching 71% today (Figure 7). As a comparison, it is estimated that roughly 50% of all articles are currently freely available in some fashion[47].

Thus the European institutions including the Commission, the Council and the Parliament, as a policy makers should show their continued support to the transition toward Open Science by a combination of new incentives and regulations in favour of Open Science.

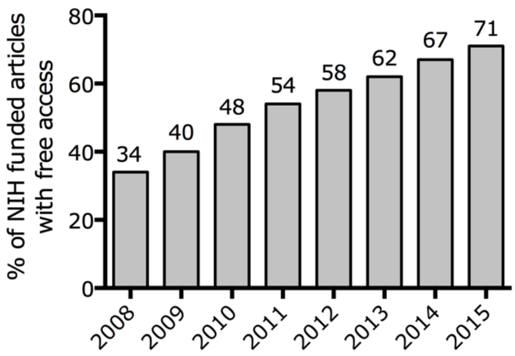

Figure 7. The rise in the proportion of NIH-funded articles that are made freely available through the Pubmed Central platform in response to the open access policy adopted in 2008. Data produced by Heather Morrison[48].

Economic factors. University libraries cannot keep up with the strong inflation in subscription costs (Figure 8). This is illustrated by Harvard University's 2012 memorandum stating that its libraries could not keep up with the price increase and that the university's faculty should favour open access publishing[49]. This is also important for most researchers in developing countries that cannot afford journal subscriptions and are thus limited to open access scholarly literature.

The economic gains for societies transitioning to Open Science are still speculative, but are predicted to be substantial. Because Open Science could increase the long-term returns on investment in research, most public and private research funders are strong supporters of the Open Science movement. More concrete evidence of the economic impact of Open Science will reinforce this trend in the near future.

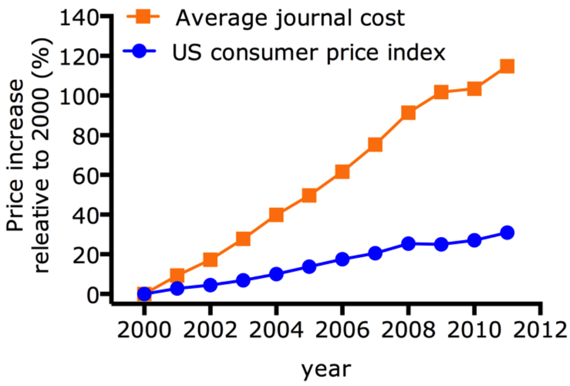

Figure 8. The average price increase of health sciences journals from 2000 to 2011. This data was collected by the University of California San Francisco libraries[50].

3.2. Forces restraining Open Science.

Although the transition towards Open Science has already begun, several forces have slowed its implementation. Below, we identify some of the main barriers to Open Science and how these can be overcome.

Cultural resistance to change. In many scientific fields, there is a cultural heritage of secrecy around research projects. Researchers are concerned about informing competitors on their projects before an official publication undoubtedly credits them for their ideas and accomplishments. Hence research proposals, reports of recent progress, and details about awarded grants are not commonly shared. Even some publications are voluntarily vague about details for fear of losing an expertise monopoly that provides an advantage over a competing group. Another reason for secrecy is the rather individualistic nature of academic research. Team projects are rare; all graduate students are required to have first-author publications to succeed, and professors are judged solely on their publications and successful grant application records. In the private sector, both culture and technical barriers prevent organisations from sharing R&D results such as clinical trials.

Research is also too often kept behind the walls of research laboratories. Research projects are seen as too technical and difficult to be understood by a layperson. Thus traditionally, researchers do not communicate directly with the general public about their activities.

The fears associated with sharing research data and ideas can be lifted with changes in the evaluation and reward system of researchers. Researchers should be evaluated on their collective achievements (as well as on their personal ones), and a trustworthy system to undoubtedly attribute authorship to all research outputs, before or after publication, must be established. Rewarding outreach activities will bring science and society closer together, and could help researchers re-evaluate themselves as producers of knowledge for the common good. This would in turn reinforce their willingness to openly share their findings.

Distrust in the new forms of publications. The re-appropriation of ideas in scientific research is common and even necessary. It is also at the core of Open Science practices. However, it cannot be done without giving proper credit. Unfortunately, researchers engaging with new forms of publication such as blog posts, comments, and research outputs uploaded to open repositories are not guaranteed to receive credit for their work. These outlets stand on the margin of the more official publication system, lacking recognition, trust, and regulation. This is first because there are no metrics taking into account these outputs of research results in the evaluation of researchers. That will change with the advent of new metrics as detailed in Chapter II. Second, there is a fear that the lack of regulation on these platforms exposes the authors to the wrongful appropriation of their work.

These barriers can be overcome by a system that unequivocally identifies the time and authors of any published research outputs. Using secured verification methods currently used by banks would guarantee the identity of the author. For instance unique verification codes could be sent to the user's mobile phone. This system would be linked to ORCID-type profile page[45] to create a verified, centralized, and public record of the scientific outputs produced by an individual across all online platforms. This public record will discourage anyone from wrongfully claiming authorship. As a consequence, trust will be instated in the alternatives to traditional journals, allowing faster and more open sharing of research results.

Lack of information on Open Science. Open Science is sometimes viewed as an idealistic movement and not as a pragmatic solution to critical shortcomings of the research ecosystem. It is also considered as too time-consuming for researchers to implement, with no concrete gains in return. If the value of engaging in Open Science is not made self-evident, researchers will prefer to spend time publishing and fundraising, two activities that have a direct and short term impact on their research group and on their career. In addition, there are concerns associated with the new digital tools that enable Open Science. For instance the security of data when it is stored in remote locations such as data repositories owned by private firms is often questioned. There are also misunderstandings as to whether these new tools and practices can be compatible with intellectual property requirements. For instance, it is often unclear to researchers whether electronic signatures in electronic lab notebooks can be used to prove an invention's conception date.

Information about what Open Science can concretely mean to researchers and what immediate and long-term gains they can expect would help resolve these issues. Many researchers have already adopted some Open Science practices without realizing it. Introductions to the tools that facilitate data sharing and more open communication could help them reinforce these practices.

Lack of incentives for researchers. In combination with a cultural barrier and a lack of information, academic researchers in particular have few incentives to adopt Open Science practices. Indeed, career advancement relies mostly on the number and quality of publications, and not on the reproducibility, availability, and re-usability of research results (which Open Science practices guarantee). The time and effort currently required to deposit data in repositories, to launch a crowdfunding campaign, or to publish blog posts is significant. For instance one researcher calculated that he spent 36 additional hours and 690 US dollars in order to make the data of a single paper available to all[51]. These activities risk not being recognised by employers as equally valuable as other more traditional research activities.

Another deficit in incentive comes from some of the digital tools developed for researchers. They may have the potential to profoundly impact research, but many provide little immediate benefit. Google, for instance, has mastered the art of incentivising users to share large sets of private information by providing clear and immediate benefits in the form of well-crafted services (email, data storage, search engine). Similar approaches must be taken into consideration by tools enabling Open Science to provide strong incentives for researchers to become regular users.

Lack of standards and the existence of uncertainties around Open Science services. Over the past 5 years, the offer in electronic lab notebooks, collaborative writing tools, or reference managing tools has become somewhat overwhelming in several ways. First, it is difficult for researchers to evaluate if the solution fits their needs before they invest significantly in time and funds. And second, the majority of these tools are developed by small start-ups that can close their services without warning if investors do not regularly renew their support. The risk of losing data or having to transfer the data to other services is thus perceived as high. For instance, digital laboratory management tools and laboratory notebooks require inventories, protocols, and experiment reports to be entered manually in a particular format. Although exportable as read-only files (such as PDF), it is often impossible to re-import the data in a competitor's solution.

To address these issues, standards need to be agreed-on to improve the compatibility between platforms. Each company should prepare a user data recovery plan in the case of service closure. This would facilitate the change of service provider, thus lowering the perceived risks and encourage more researchers to adopt these new tools.

Immature and non-sustainable Open Science public infrastructure. Although Europe's Internet infrastructure is one of the most advanced in the world, big data transfer can still be challenging. The Beijing Genomic Institute (Shenzen, China) produces over 6 terabytes of genomic data every day. Even broadband Internet connections do not allow the transfer of such large amounts of data to data repositories in Europe and around the world within a reasonable time. With a 100 megabit per second connection it would take over 5 days to make the transfer. Many researchers still resort to sending hard drives by mail to the data repositories, which entails risks of damaging or losing the data[52]. In addition to the inapt data transfer infrastructure, many universities still do not offer data management solutions to their researchers. This will soon become unsustainable, as more research funders require that a credible data management plan be included in the grant proposals. From the existing commercial solutions for research data storage, many are based outside the EU, mostly in the United States. Possible concerns about data sovereignty and confidentiality when it is stored by non-European based companies, should serve as an incentive to develop European turnkey research data management solutions for research organisations.

Public infrastructure in a fully implemented Open Science world would comprise a wide variety of services such as software and hardware solutions to accelerate big data transfer speeds, open repositories for research outputs, as well as pre- and post- publication peer review and commenting platforms. Already a post-publication commenting platform has been launched by NIH's Pubmed in 2013[53] and a data repository called Zenodo[54] was launched by the European Commission in 2014. These tools and others to come need to continuously evolve to accommodate new technologies and user needs. They will also need to be funded by more permanent funding schemes to guarantee their perennity.

Cost. The direct and indirect costs of implementing Open Science practices are a barrier for research institutions and researchers. For institutions, it includes investments in infrastructure (servers, networking capabilities, software) and personnel to support researchers (librarians and data curators). For researchers, the cost comes from the time invested in organizing and disseminating data, outreach programs, and Open Access publishing fees.

In addition, most Digital Science tools use a software-as-a-service model, which consists in providing access to the software through an Internet browser but not to the executable file. The advantages of such a model are instant access to the service, scalability, and constant updates. However, typical lab management software, reference managers, or file storage services cost around $5-10 per month and per user. As researchers adopt more of these tools the cost could become significant. As an alternative, many of these services could be managed by the research institutions that would federalise cost and benefit from economies of scale.

CHAPTER IV – SCENARIOS AND POLICY OPTIONS

This final chapter provides a picture of the European research and innovation ecosystem in 2030, when Open Science is fully implemented. We focus on three aspects of the Open Science transition, including the redefinition of the interactions between the stakeholders of the research and innovation system, the impact of Open Science on Open Innovation, and the identification of the stakeholders that will benefit or lose from such changes. Finally, we end with a fourth section describing a set of policy actions that the European Commission, Council and Parliament, as well as the member states can implement to reach the full potential of Open Science.

4.1. Open Science will redefine the interactions between the main stakeholders of the research and innovation system.

Open Science and the opportunities it represents will profoundly affect the interactions between the main stakeholders of the research and innovation system. Here we investigate the changes between researchers, the private sector, and the general public, between researchers and publishers, between researchers and research institutions, between European institutions and other countries, and between digital science companies and the public sector.

In 2030, researchers, the private sector, and the general public are much closely interconnected than today. Researchers are directly connected to companies interested in their expertise and innovations through Open Innovation digital platforms. The research outputs are made automatically available in meaningful formats to any organisation interested in their work. With science being more open, new opportunities for researchers to interact with the general public have emerged. For instance, educators are using reports of recent advances in research, and the most spectacular scientific research is broadcast in near-real time to followers, making science a popular spectacle.

In 2030 the peer-review process is now open, profoundly changing the relationship between researchers and publishers. Peer review has adapted to a new form of scientific publishing, consisting of self-publishing of virtually any type of file (raw data, code, images, text, and so forth) in mega-journals, data repositories, or published on the web by other means (such as blog posts). Smart systems automatically suggest a series of reviewers for each document. Unbiased, these algorithms find the best match between the document’s content and the reviewer’s publication and review history. Thus the role of journals, journal reputation, and journal editors has become less prevalent. Publishers have transformed into service providers, extracting metadata and measuring the impact of published documents. They also help researchers communicate their findings, both to scientists and the general public.

The relationship between researchers and research institutions will also have changed in 2030. Although most researchers remain hosted by institutions that provide teaching opportunities and a rich research community, others are not affiliated to a particular institution. Open Science has allowed virtually anyone to conduct science in close connection with the scientific community, without needing to be integrated in the traditional network of research institutions and universities. Ethan O. Perlstein is a recent example of a Harvard and Princeton-trained scientist that established an independent research group working on drug discovery[55]. He perceived his chances of obtaining a tenured position and sustainable funding to carry on his work in this novel field very slim. He thus started a crowdfunding campaign to begin his own independent laboratory. Such independent researchers seek funding from a combination of public funders and private investors. Very similar to start-ups, they focus on resolving scientific problems that also have economic value. They heavily rely on subcontracting to replace services of academic institutions such as lab management and access to instrumentation. Open Science has given researchers more independence with respect to their research institutions.

With Europe leading the way in Open Science, European countries have gained a competitive advantage over countries that delayed their transition towards Open Science. Providing research results freely to the world has increased the international visibility of European research and favoured collaborations with developing countries. The European Union, through the actions of the European Commission, has lead the way by building the necessary Open Science infrastructure and establishing standards that are now used by many other countries throughout the world. European science policies are regarded as standard and have profound impact on the international research ecosystem.

The societal and economic promises of Open Science rely heavily on innovative tools able to extract value out of the massive amounts of data made available. In 2030, software companies enabling Open Science have become central players of the research ecosystem. Their tools now connect all stakeholders of the research and innovation ecosystems, by storing and analysing data, and by facilitating communication. The public sector closely collaborates with these companies to set standards, ensure ethical conduct, and assure that their investments are complementary to those made by the public sector.

4.2. To what extent can Open Science foster Open Innovation?

In this section, we describe how Europe's embracement of Open Science has impacted Open Innovation in 2030. Through a series of scenarios, we demonstrate how Open Science will help new ideas to be generated and funded.

It is the year 2030; a group of researchers has spun off a small biotechnology startup to develop a new anticancer treatment targeting a recently discovered protein. The startup has easily accessed the results of chemical screenings that others have already conducted through extended versions of today's EU-Openscreen database[56], and, within mere weeks, at very low cost, this group has narrowed its candidate molecules. The company has also free access to very detailed experimental protocols, which has accelerated its endeavour. Open lab notebooks, associated with powerful algorithms, help the researchers troubleshoot their experimental difficulties by analysing problems previously solved by other scientists throughout the world. The startup also subscribes to an Open Innovation platform that connects companies with the stakeholders of the innovation ecosystem. The platform puts the startup in touch with researchers working on similar issues, automatically suggesting funding opportunities, assembling consortiums for European projects, and reminding them of conferences that potential partners will also attend. Investors and larger companies, which are on the lookout for new ideas and technologies to invest in, are also connected to these platforms. By embracing Open Science, the small company has access to valuable knowledge, and is immediately connected to the innovation ecosystem, saving time and money that would have been lost in technical difficulties and more tedious networking.

Early on, this startup began to research the regulatory constraints it faces. Regulatory agencies have also opened their data and can be connected to the live feed of information from the startup's R&D activities to generate regulatory advice. For instance, several components used in the formulation for their anticancer drugs might have already been approved. The system will automatically inform researchers as the research is being conducted and detail what data has led to the component's approval in the past. This will allow researchers to take into account regulatory constraints and take data-supported decisions as the research is being conducted.

An academic laboratory has developed a new biomaterial that can be implanted to treat osteoporosis. Before communicating its findings, the academic lab has waited until the initial idea was patented. The open access requirements from public funders take into account the need for an embargo period in certain fields of research and in cases where confidentiality is required. However, now patented, the data that led to the invention and pre-clinical trial results are posted regularly on the Open Innovation platform. Implant manufacturers can regularly check the advancement of the project and decide to fund part of the project once enough convincing data are released. Patient groups can follow the latest advances that concern them and can decide on crowdfunding specific parts of the project. Subcontractors specialising in standardised pre-clinical trials are directly informed of the needs of the researchers and suggest their services.

Research labs are now closely connected with the general public, and citizens are taking a role in the Open Innovation ecosystem. Through systems similar to today's Twitter[57], the general public can *follow* research groups, who make regular announcements about their findings in layman's terms, providing links to data, figures, protocols, and their detailed descriptions. This new form of engagement with the general public and professionals will encourage a flow of new ideas to research groups. Industrial, societal, and environmental challenges could be brought to the attention of researchers equipped with the expertise and interest to pursue them. For instance, a surgeon might learn about the discovery of the new biomaterial developed by this academic research team, and give her impression on its actual usability, or offer to participate in pre-clinical studies.

4.3. Do particular stakeholders stand more to lose or gain from the transition towards Open Science?

In 2030, current stakeholders of the research ecosystem will all have been deeply impacted by the transition towards Open Science. Because Open Science is a response to a series of limitations with which the research ecosystem is currently confronted, more stakeholders will gain from this transition than lose. However, major transformations will occur.

Publishers. In 2030, researchers themselves or other organisations such as libraries now directly publish research outputs. The more automatised, collaborative, and open peer review system has limited the competitive advantage of certain publishers who were advertising their network of reviewers. Most publishers have needed to adapt their business model to stay afloat because of the lack of added value being offered to the researchers. Peer-review coordination and article distribution is thus no longer at the core of the publishers' activities in the year 2030. However, new business models and markets have emerged. The publisher's customers are not limited to libraries anymore, but now include research organisation administration and individual researchers. Services such as literature discovery, post-publication analysis of research data, and networking platforms are now at the core of the business model of scholarly publishers.

Acquisition date	Company name	Product/Service
June 2012	Collexis	Knowledge discovery.
January 2012	QUOSA	Literature management workflows and archives.
August 2012	Atira	Research information for research organisations.
January 2013	Knovel	Analytical and search tools for innovator and engineers.
April 2013	Mendeley	Research collaboration platform.
January 2015	Newsflo	Media impact of research papers.

Table 1. The recent acquisition of digital science companies by Elsevier, a world-leading academic publishing company.

This trend is well illustrated by the recent acquisition of six innovative companies in the digital science space by a world-leading scholarly publisher, Elsevier (Table 1). This includes the acquisition of Mendeley a social platform for researchers that claimed over three million subscribers beginning 2015.

The diversity of customers might expend even further in the future, with the expertise gain by publishers in the extraction of value from published research results. For instance one can imagine that a set of data about fossil findings published by archaeologists could be analysed and transformed into a heat map of potential natural resources for energy companies. Indeed, the experience of publishers in handling research data could help them become experts at extracting value from it.

Libraries. With the advent of Open Science, the role of libraries has significantly changed, with libraries becoming important facilitators of Open Science practices. Libraries now focus on helping researchers and students navigate and use the vast amount of freely accessible information. Librarians support research by informing their users about the best practices and technicalities for the curation and organisation of research outputs. Some libraries are also directly competing with major publishers, collecting research outputs, adding metadata, and communicating the research of their institutions.

Researchers. In 2030, with Open Science being properly implemented, researchers have benefited from the transition to Open Science. However, this was made possible with strong investments and innovation in the necessary infrastructure that allows Open Science to be conducted. Financial support, in particular in the form of specialised personnel, was also needed to limit the additional workload of researchers and avoid decreasing their scientific productivity.

Public institutions. Governments, funders, research institutions, and other governmental agencies of 2030 support the cost of Open Science, in terms of infrastructure, training, and personnel. In return, they benefit from the wealth of information at their disposal that they use to make evidence-based policy decisions, make research institutions more efficient, target funding more precisely to resolve current challenges, and help governmental agencies solve difficult problems by more transnational collaborations.

Private sector. The private sector as a whole, and small and medium size enterprise in particular, benefit from easier and less costly access to scientific knowledge produced by academic researchers. With the transition to Open Science, the private sector has become more connected with academic research, providing their R&D departments with the expertise and innovative approaches they need. Stimulated by the public engagement in Open Science, some companies have also released some of their R&D results (see Chapter II). In 2030, the cost of Open Science policies for many large private companies has been surpassed by the positive impact on the public perception of the companies, and through the new collaborations it has generated for the R&D departments.

Civil society. In 2030, citizens have gained from Open Science in several ways. They benefit from more instantaneous and more understandable access to the latest scientific information, which has increased the public support for science. Open Science benefits non-governmental organisations that use data to better tackle problems. Already today, DataKind[58], a non-profit organisation, has begun to show the power of open access to data to solve humanitarian crises and challenges. For instance, the United Kingdom Chapter of DataKind analysed public data about UK's healthcare sector and demography to map the localisation of 30,000 children with life-limiting conditions. Patient associations then used that data to better target their efforts and eventually help more children. The benefit of accelerated, more innovative, and efficient scientific research translates into better technologies, better medical treatments, more economic growth, and higher quality of life for all.

4.4. To what extent is policy action in the EU or at the national level required to avoid pitfalls and overcome obstacles?

The transition towards Open Science has already started, with countries such as the United States, the United Kingdom, and Scandinavian countries requiring open access for research publications, and soon for research data[59]. However, the evolution towards a fully implemented Open Science will require time since habits need to change, and new tools and infrastructure need to be developed. The European Commission has the unique opportunity to accelerate this transition by simultaneously providing incentives, suggesting regulations, and making concrete investments in favour of Open Science. All three aspects will be necessary to reach the goal of a fully implemented Open Science by 2030.

The European Commission needs to show its leadership role and ambition in transitioning towards Open Science by publishing clear statements about its vision of the benefit of Open Science for all stakeholders of society and the research ecosystem. The European Commission will need to act as a leader in this transition by defining a framework of incentives, standards, and policy actions for Open Science and innovation, which can then be adopted by member states of the EU. Here, we describe a three-step process that would allow Open Science to be fully implemented.

Phase I: Enable the transition towards Open Science

In a first phase, the European Commission will extend its efforts in the promotion of Open Science. The policy propositions made here still acknowledge the current publishing model and research ecosystem, but enable and encourage researchers to perform Open Science without being penalised.

Require open access for published articles and data. As a major funder of European research, the European Research Council (ERC) should require all data and published articles to be accessible by all through online platforms. The European Commission should recommend all member states to adopt similar practices. In addition to the data embedded in articles, the ERC should encourage all raw data and unpublished data to be stored in open repositories such as Zenodo[54]. Copyright laws and policies should be adapted to allow data and text mining of published research outputs.

Fund open access. Payment of open access fees by researchers is a psychological and practical barrier to the choice of publishing in open access. Publishing costs are currently taken directly from grants and give the impression of reducing available funds for research. Instead, the ERC could put in place an open access fund that, after request from the researcher, could subsidize open access publishing. Through agreements between the publishers and the ERC, the authors would simply submit a request for financial support to open access publication. The subsidy can be modulated by the ERC to encourage researchers to publish in pro-open access scholarly journals. The publisher will then charge a fraction of the price to the researcher, the other being paid directly by the ERC.

In parallel, discussions between the EC and publishers should determine fair prices for open access and journal subscription costs. Although the ERC has been indirectly funding the scholarly publishing industry for years, there has been no direct negotiation of the prices. The open access subsidy to researchers would place the EC as a major client of publishers and would provide the ERC with negotiation leverage to first decrease the current prices, then control the publishing costs that have been increasing constantly over the past 15 years (Figure 8). The EC could also encourage publishers to adopt more Open Science friendly policies by modulating the level of its subsidies. This policy can only be implemented after a negotiation process that should include all actors of the scholarly publication industry.

Support Open Science practices. The implementation of Open Science will represent a significant additional workload for the researchers. Data curation, classification, and annotation will be automatic tasks in the future, but are still mostly done manually today. Opening research to the general public through social network activities and other outreach activities also requires time and expertise. In coordination with member states and research institutions, the EC and the ERC should support researchers and research institutions that wish to fully engage in Open Science practices.

Concrete examples of actions in this domain could include the establishment of clear roadmaps on how to prepare and encourage the transition towards Open Science within research organisations. These could be similar to League of European Research University's roadmaps that provide advice to universities on a variety of issues such as research data management and open access[60]. The ERC should also fund personnel that will help researchers and research organisation in tasks related to Open Science. For instance, research data managers and outreach coordinators should be systematically covered by ERC grants. The help could also come in the form of free services for ERC grantees. For instance, a team of graphic designers and communication specialists could help researchers design clearer figures in their research papers and to create infographics to better communicate their research to the public. These services would represent an infinitesimal fraction of the ERC budget but would drastically increase the impact of the research it funds.

Build a sustainable Open Science infrastructure. The EC and ERC should invest in the necessary infrastructure to enable Open Science. Free access to repositories accepting all types of digital files resulting from research activities should made available. Repositories currently lack visibility and trust from many researchers, which has been limiting their adoption. To guarantee the perennity of the data, the infrastructure should be made sustainable by avoiding project-based funding. Agreements with research institutions and member states should be sought to guarantee long term funding.

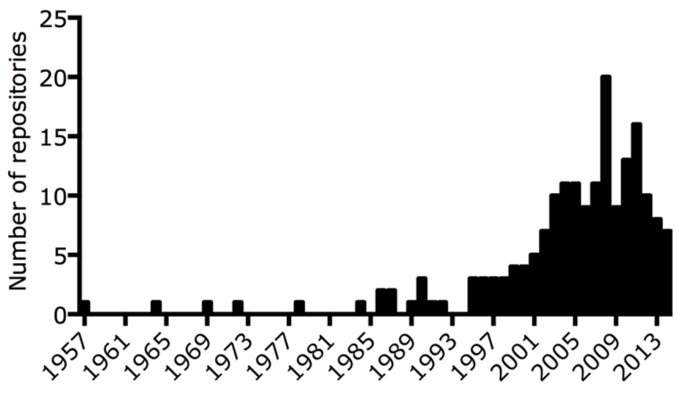

Figure 9. Number of new data repositories in France and Germany per year. The data were extracted from the re3data[61] data repository.

Over the past 10 years, the number of data repositories launched throughout the world has increased significantly (Figure 9). With little coordination, each scientific field has developed its own repository, using a variety of backend technologies and user interfaces. Although a testament to the developing interest in data repositories, these lack visibility and are often unknown to researchers. As of May 2015, re3data[61] counted nearly 1,200 registered repositories worldwide. Research organisations of the EU are major actors in this field, with 637 repositories originating from one of the EU member states. This number is close to the 636 repositories supported by institutions of the United-States (Figure 10).

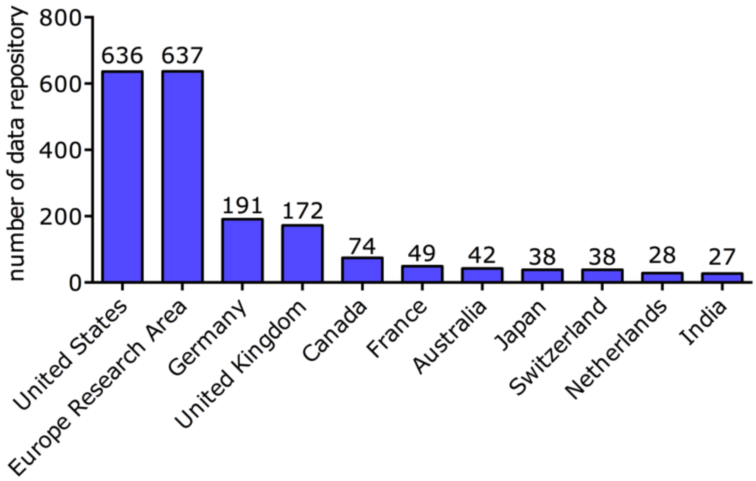

Figure 10. Geographical localisation of organisation supporting data repositories. The data were extracted from re3data[61] in May 2015.

Increasing the visibility and ease of use of such repositories could help generalize their use and encourage researchers to systematically deposit their data. The EC should coordinate the federalisation of European data repositories to maximise their visibility and usability. This model preserves the existing infrastructure and uses a series of common standards to link all repositories to a single user interface.

Along with setting standards for a federalised repository system, the EC could provide specific grants for developing Open Science infrastructure aligned with the Open Science framework developed by the EC. For instance, proper access to data repositories might require institutions to upgrade their Internet access to satisfy the large data generators and users. Local investments should be tracked by the EC Open Science observatory and encouraged by an EC Open Science label, in recognition of the investments in Open Science infrastructure made by institutions.

Similarly to the EC's push for the use of digital data repositories with Zenodo, the EC could offer an electronic lab notebook. Lab notebooks are central to the researcher's workflow and could be interconnected with many of the Open Science tools that exist and will exist in the near future. This could prove to be a valuable strategic investment in terms of infrastructure and in promoting the changes in mindset towards acceptance of Open Science practices.

Stimulate a nascent European digital science industry. Open Science is enabled by a series of innovative digital tools that allow information to be shared and analysed more easily. The emerging digital science industry is investing in the infrastructure of tomorrow's Open Science. As such, the digital science industry is becoming an essential player in the transition towards Open Science. Fuelled by the prospect of Open Science, an exponentially increasing number of new digital science companies have been founded over the past 15 years (see Figure 11).

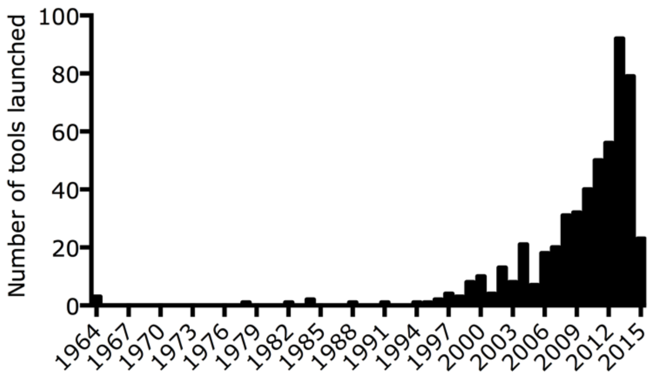

Figure 11. Digital science startups founded over time, worldwide. Data obtained from the list of digital tools for researcher available on the ConnectedResearchers[62] and 400+ Tools and innovations in scholarly communication websites[63].

However, the geographic distribution of these innovative companies is unequal throughout the world. 67% of digital science companies were founded in the United States, while only 28% in Europe (Figure 12). The EU now risks becoming largely dependent on US-based companies for the proper functioning of its research activities.

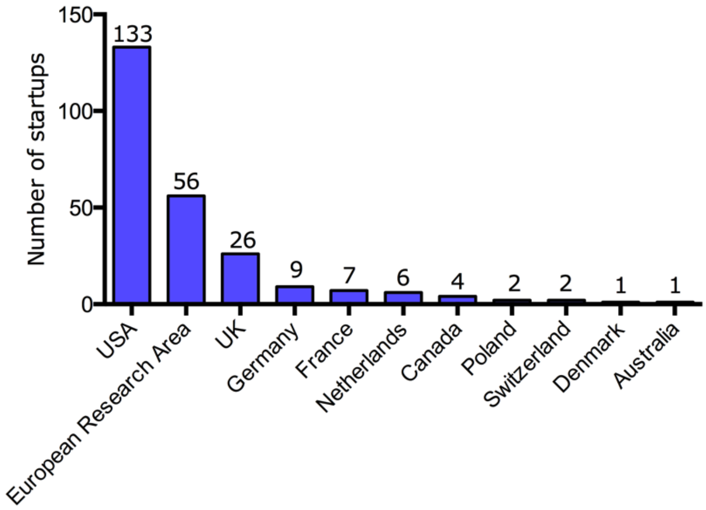

Figure 12. Geographical localisation of the digital science startups as of May 2015. Data obtained from the list of digital tools for researcher available on the ConnectedResearchers[62] website.

The EC should encourage digital science companies and startups to invest in the Open Science infrastructure by including them in calls for Open Science infrastructure grants. The EC should also discuss with digital science companies the elaboration of a code of ethics, covering data usage and closure-of-service strategies that guarantee the sustainability of the research data. The EC should also encourage the creation of a European network of digital science startups to stimulate this ecosystem.

Inform and train*.* As Open Science practices becomes more prevalent, efforts should be made to build awareness of the opportunities it represents for researchers and society. First, the EC should make clear statements about its efforts to develop Open Science in Europe. This should be combined with online and local communication campaigns explaining how specific Open Science practices can make the work of researchers more efficient and impactful. Toolkits, tutorials, and courses should be prepared for universities and research groups with the desire to increase the openness of their research. These could explain the immediate and long-term positive impact of Open Science practices and introduce stakeholders to the tools enabling Open Science. Amongst such educational resources, massive open online courses (MOOCs) could be a relatively low-cost solution, in particular to reach young researchers. These could provide testimonies from researchers practicing Open Science and provide hands-on experience with digital tools for researchers. The few initiatives that already exist now need to be multiplied and extended upon (Table 2).

The growth in the number of digital tools for researchers and the frequent release of new services can be disorientating for researchers. An online platform to help researchers find and use the tools that fit their needs would help increase adoption rates. Expanding on already existing lists of digital tools for researchers (DIRT[64], 101 innovation in scholarly communication[65], Force11[66], Connected Researchers[67]), the platforms would include tool presentations, reviews, and tutorials. Training should not only focus on researchers, but also on other stakeholders such as librarians. Several initiatives have started to prepare librarians for more open and data-intensive scientific research. The Data Scientist Training for Librarians program[67] is training librarians to respond to the growing data-related needs of researchers. Developed by the Harvard-Smithsonian Center for Astrophysics John G. Wolbach Library and the Harvard Library, it teaches Librarians to capture, handle, prepare, analyse, and visualise data. Although it is a data-centred course, Open Science practices are at its heart as illustrated by the introductory sessions on metadata management and on collaborative platforms such as GitHub. Once trained, these librarians could then help doctoral schools instruct young researchers on how to handle and collaborate around data in an Open Science spirit. Already 120 librarians have been trained in three sessions, and the first European version is set to happen in Copenhagen in 2015. Similar events could be generalized throughout Europe.

Name of MOOC	Language	URL
Numérique et recherche en santé et sciences du vivant	French	https://www.france-universite-numerique-mooc.fr/courses/VirchowVillerme/06005/session01/about
Open Science Training Initiative	English	http://opensciencetraining.com
Open Science: An Introduction	English	https://courses.p2pu.org/nl/courses/5/open-science-an-introduction
FOSTER portal	English	https://www.fosteropenscience.eu

Table 2. List of MOOCs and other educational resources dealing with Open Science practices.

Phase II: Open the way to fully implemented Open Science

The first phase will have set the conditions for Open Science to develop. Although still a minority, researchers will have started opening their research outputs and embracing Open Science. In a second phase, the transition towards Open Science will need to be sustained by major changes in the reward system and incentives of the academic research system.

Provide field-specific guidelines for opening all aspects of the research lifecycle. The EC and the ERC, as major research funders, need to provide clear instructions to the researchers it funds regarding the dissemination of research results. After a large-scale consultation of Academies of Sciences from member states, field-specific guidelines for research accessibility should be put into application, becoming a requirement for all ERC research grants. The default should be the openness of all research output, including lab notebooks, reports, and grant applications. Specificities will need to be addressed to allow patents to be deposited. This policy action can only be taken in full coordination with the following action.

Adopt standards for the recognition of authorship and metrics of impact of data published in non-traditional forms. As research data is opened, as publishing research output becomes more instantaneous, and as publishing takes on a variety of formats (lab notebooks, blogs, pre-prints…), the authorship of each published document should be easily and clearly defined, and traceable. This is to abolish the fear of plagiarism, or identity theft, which is a major barrier to the adoption by researchers of Open Science practices.

The EC should adopt a set of standards for tracking and attributing research outputs. Solutions such as the ORCID project[45] have already started to be accepted as standard by researchers and publishers.

Encourage and reward open peer-review of the published research output. With the multiplication of published research output, the scientific validation process will have to adapt. Depending on the field, and on the type of document published, quality control of research results could continue to take the form of reports written by peers, or could take the form of online commenting and automatic metrics. In all cases, the peer review system should be made more open and transparent to rebuild trust between all stakeholders of the research ecosystem.

The EC and ERC should recognize peer review as being at the core of the researcher's activity, and as being an important criterion for the researcher's evaluation. ERC individual grants award criteria should be adjusted accordingly. Tools that keep track of the number of reviews and evaluates their quality should be developed, and then validated by the EC as career evaluation tools. Early versions of such services have already been launched (List 16).

Encourage private companies to embrace Open Science practices. Private companies invest 162 billion euros in research and development yearly[68] in Europe; unfortunately, only a small fraction of the knowledge produced is made available to the public. Although Open Science is clearly more applicable in academic settings where economic competition is not the norm, many private R&D projects have lost their economic value and could be shared without jeopardizing earning for the company. The EC could play the role of mediator between major private investors in R&D to help eliminate the sometimes-irrational fears or negative habits associated with data sharing.

Such action could include EC-mediated negotiations between companies to agree on the scope and timing of research data release. The EC could launch public calls for data donation in fields where researcher are lacking data. The donors would get publically credited for it, thus encouraging participation. The EC could also launch a European inventory of private R&D data by asking companies to provide a description of the data they have at hand and by assisting them in doing so. Such database would encourage researchers to engage with new industrial partners. The conditions for the release of the data would then be subject to further negotiations.

Phase III: Extract value from Open Science

Phase II will have led to the full implementation of Open Science. The transition towards Open Science will have created more inclusive, more efficient, and more productive research. But it is also a stimulator of innovation, which creates both public and private value. The return on the investments made by the EC in Open Science will greatly depend on the capacity of European institutions and member states to stimulate the exploitation of the vast amount of knowledge made available. In this third phase, a series of policy actions is suggested to ensure this.

Connect companies and NGOs with the researchers and research results. The creators of industrial and societal value, mainly private companies and NGOs, should be able to easily access research outputs. They should also be encouraged to interact more closely with the researchers who generated the data and who could provide their expertise and creative input. Academic research, because of its history of being published behind paywall and written in a language that can be complicated for a layperson, has not traditionally been a go-to resource for SMEs and NGOs. With Open Science, the companies should be made aware and given full access to the richness of academic research.

The EC can help companies and NGOs exploit academic research and expertise by favouring interactions through open innovation platforms that would allow all to easily access competencies and data generated by European researchers.

Create a European space for knowledge and expertise. European countries share rivers, traffic flows, airborne pollutants, urbanisation problems, and to a great extend the same way of life. A large number of national agencies scattered throughout Europe gather and analyse large amounts of data to help them best meet these challenges. For instance, water temperature, pollutant levels, and flow rates measured on the Danube River in Germany could be complementary to those registered in Bulgaria to better exploit and manage the river. However the data collected is often hard to access for researchers and other agencies because of a lack of awareness, standardisation, and infrastructure.

The EC could provide incentives for them to share the data they collect, for instance by requiring EU-funded infrastructures to generate open data. The EC should favour the interaction of agencies by forming virtual European agencies, where data will be shared and discussed to solve common challenges.

Nourish the digital science start-up ecosystem. Digital science companies, in addition to being an essential part of the Open Science infrastructure, are also sources of innovation in research. By helping researchers to be more efficient and by bringing new ways to analyse and use research data, these companies will be catalysts of progress.

The EC should stimulate the emergence of new digital science companies through a combination of grant-based funding and direct the financing of investment funds specialised in this sector. This would compensate for the inherent uncertainty tied to such a new sector and the traditional risk aversion of European investors. The EC should also work with the digital science industry to elaborate new copyright laws to ensure that copyrighted content can be accessed for text mining purposes.

REFERENCES

1. Schneegans, Susan, ed. (2010) *UNESCO Science Report 2010: The Current Status of Science Around the World.* Unesco Publishing [online]. Available from: http://www.unesco.org/new/en/natural-sciences/science-technology/prospective-studies/unesco-science-report/unesco-science-report-2010

2. Addgene [online]. Available from: https://www.addgene.org

3. Researchgate [online]. Available from: https://www.researchgate.net

4. Academia [online]. Available from: https://www.academia.edu

5. Neylon, C. and Oaspa (2013) *Growth of Open Access - Major Publishers. figshare* [online]. Available from: http://dx.doi.org/10.6084/m9.figshare.650799.

6. Datacite. Available from: https://www.datacite.org/.

7. Pscheida, D., Albrecht, S., Herbst, S., Minet, C. and Köhlerk, T. (2014) Nutzung von Social Media und onlinebasierten Anwendungen in der Wissenschaft.

8. Vignolii, M. (2014) *YEAR Consultation on Science 2.0* [online]. Available from: https://scienceintransition.files.wordpress.com/2014/12/year_consultation_science-2dot0_v1-0.pdf

9. The IPython Notebook [online]. Available from: http://ipython.org/notebook.html.

10. Science Exchange [online]. Available from: https://www.scienceexchange.com

11. Overleaf [online]. Available from: https://www.overleaf.com

12. Publons [online]. Available from: https://publons.com

13. Rubriq [online]. Available from: http://www.rubriq.com

14. SciStarter [online]. Available from: http://scistarter.com

15. Zooniverse [online]. Available from: https://www.zooniverse.org

16. Ma thèse en 180 secondes [online]. Available from: http://mt180.fr

17. Ask a Scientist [online]. Available from: http://askascientist.co.uk

18. Ask An Engineer | MIT School Of Engineering [online]. Available from: http://engineering.mit.edu/ask

19. NPTRUST [online]. Available from: http://www.nptrust.org/philanthropic-resources/charitable-giving-statistics/

20. EFC (2013). *European Foundation Centre Annual Report and Financial Statement*.

21. MIT-industry-knowledgebase [online]. Available from: http://ilp.mit.edu/expertise.jsp

22. Patent search at CALTECH [online]. Available from: http://innovation.caltech.edu/patent-search

23. Research Connection [online]. Available from: https://www.researchconnection.com

24. Madjarevic, N. & Davies, F. (2015) Altmetrics in Higher Education Institutions: Three Case

Studies. *The Winnower*

25. CHEMLab boot camp [online]. Available from: http://ocw.mit.edu/high-school/chemistry/chemistry-lab-boot-camp/

26. Uberresearch [online]. Available from: http://www.uberresearch.com/

27. Dahn, B., Mussah, V., and Nutt, C. (2015) Yes, We Were Warned About Ebola. 7 April. *The New York Times* [online]. Available from: http://www.nytimes.com/2015/04/08/opinion/yes-we-were-warned-about-ebola.html

28. Yozwiak, N. L., Schaffner, S. F. & Sabeti, P. C. (2015) Data sharing: Make outbreak research open access. *Nature.* 518, p. 477–479.

29. Houghton, J., Swan, A. & Brown, S. (2011) *Access to research and technical information in Denmark*. Report to The Danish Agency for Science, Technology and Innovation and Denmark's Electronic Research Library.

30. Swan, A. (2008) *Study on the availability of UK academic "grey literature" to UK SMEs: Report to the JISC Scholarly Communications Group.* University of Southhampton.

31. Data transparency at GSK [online]. Available from: http://www.gsk.com/en-gb/our-stories/how-we-do-randd/data-transparency

32. Open Lab Foundation [online]. Available from: http://www.openlabfoundation.org

33. Karamitsios, A. (2013) Open Innovation in EVs: A Case Study of Tesla Motors.

34. Ghosh, R. A. (2006) *Economic impact of open source software on innovation and the competitiveness of the Information and Communication Technologies (ICT) sector in the EU.*

35. GitHub [online]. Available from: http://github.org

36. Experiment [online]. Available from: http://experiment.com

37. Myprojects – Cancer research UK [online]. Available from: http://myprojects.cancerresearchuk.org/

38. Kaggle [online]. Available from: https://www.kaggle.com/

39. Innocentive [online]. Available from: http://www.innocentive.com/

40. Symplur analytics. [online]. Available from: http://www.symplur.com/

41. Number of Authors per MEDLINE/PubMed Citation [online]. Available from: http://www.nlm.nih.gov/bsd/authors1.html

42. Adams, J. (2013) Collaborations: The fourth age of research. *Nature* **497,** 557–560

43. AdminProject [online]. Available from: https://www.adminproject.eu

44. OpenAIRE [online]. Available from: https://www.openaire.eu

45. Orcid [online]. Available from: http://orcid.org

46. Suber, P. (2008) An open access mandate for the National Institutes of Health. *Open Med.* 2, p. 39–41.

47. Éric Archambault, Didier Amyot, Philippe Deschamps, Aurore Nicol, Françoise Provencher, Lise Rebout & Guillaume Roberge. *Proportion of Open Access Papers Published in Peer-Reviewed Journals at the European and World Levels—1996–2013*. (Science-Metrix, 2014).

48. Morrison, H. (2014) Dramatic Growth of Open Access V9. [online]. Available from: http://hdl.handle.net/10864/10660

49. *Faculty Advisory Council Memorandum on Journal Pricing* [online]. Available from: http://isites.harvard.edu/icb/icb.do?keyword=k77982&tabgroupid=icb.tabgroup143448

50. UCSF library *UCSF Journal Subscription Costs* [online]. Available from: http://www.library.ucsf.edu/services/scholpub/journalcosts

51. Bruna, E. M. (2014) The opportunity cost of my #OpenScience was 36 hours + $690 (UPDATED). [online]. Available from: http://brunalab.org/blog/2014/09/04/the-opportunity-cost-of-my-openscience-was-35-hours-690/>

52. Marx, V. (2013) Biology: The big challenges of big data. *Nature* **498,** 255–260

53. PubMed Commons [online]. Available from: http://www.ncbi.nlm.nih.gov/pubmedcommons

54. Zenodo [online]. Available from: http://zenodo.eu

55. Perlstein Lab [online]. Available from: http://www.plab.co

56. EU-OpenScreen [online]. Available from: http://www.eu-openscreen.eu

57. Twitter [online]. Available from: http://twitter.com

58. DataKind [online]. Available from: http://DataKind.org

59. Country responses to the OECD Science, Technology and Industry Outlook 2012 policy questionnaire and OECD (2010), OECD Science, Technology and Industry Outlook 2010, OECD, Paris.

60. Publications – LERU [online]. Available from: http://www.leru.org/index.php/public/publications/category/advice-papers

61. Re3data [online]. Available from: http://re3data.org

62. Connected Researchers [online]. Available from: http://connectedresearchers.com

63. Kramer, B. & Bosman, J. 400+ Tools and innovations in scholarly communication [online]. Available from: http://bit.ly/innoscholcomm-list

64. DiRT Directory [online]. Available from: http://dirtdirectory.org

65. Kramer, B. & Bosman, J. (2015) 101 Innovations in Scholarly Communication - the Changing Research Workflow. *figshare*

66. Catalog. *FORCE11* [online]. Available from: https://www.force11.org/catalog

67. Data Scientist Training for Librarians [online]. Available from: http://altbibl.io/dst4l/

68. Héctor Hernández, Alexander Tübke, Fernando Hervás, Antonio Vezzani, Mafini Dosso, Sara Amoroso, Nicola Grassano. (2015). The 2014 EU Industrial R&D Investment Scoreboard.

ANNEXES

List 1. Search engines and curators

- BibSonomy (http://www.bibsonomy.org) Share bookmarks and lists of literature.
- CaptoMe (http://www.bibsonomy.org) Metadata platform with rich biomedical content and information management tools for well-organised research.
- CiteUlike (http://www.citeulike.org) Search, organise, and share scholarly papers.
- Colwiz (https://www.colwiz.com) Create citations and bibliography and set up your research groups on the cloud to share files and references.
- ContentMine (https://www.colwiz.com) Uses machines to liberate 100,000,000 facts from the scientific literature.
- DeepDyve (https://www.deepdyve.com) Instant access to the journals you need.
- EvidenceFinder (http://labs.europepmc.org/evf) Enriches your literature exploration by suggesting questions alongside your search results.
- F1000 (http://f1000.com) Leading biomedical experts helping scientists to discover, discuss, and publish research.

- Google Scholar (http://scholar.google) Provides a way to broadly search for scholarly literature across disciplines and sources.
- LazyScholar (http://www.lazyscholar.org) Chrome extension to help your literature search.
- Mendeley (http://www.mendeley.com) A unique platform comprising a social network, reference manager, article visualization tools.
- Microsoft Academic Search (http://academic.research.microsoft.com) Find information about academic papers, authors, conferences, journals, and organisations from multiple sources.
- MyScienceWork (https://www.mysciencework.com) Diffuse scientific information and knowledge in a free and accessible way.
- Nowomics (http://nowomics.com) Follow genes, proteins, and processes to keep up with the latest papers and data relevant to your research.
- Paperity (http://paperity.org) Aggregator of open access papers and journals. Search engines and curators.
- Paperscape (http://paperscape.org) Visualise the arXiv, an open, online repository for scientific research papers.
- PubChase (https://www.pubchase.com) Life sciences and medical literature recommendations engine.
- Pubget (http://pubget.com) Search engine for life-science PDFs.
- PubPeer (https://pubpeer.com0 Search for publications and provide feedback and/or start a conversation anonymously.
- ReadCube (https://www.readcube.com) Read, manage, & discover new literature.
- Scicurve (http://scicurve.com) Transforms systematic literature review into interactive and comprehensible environment.
- Sciencescape (https://sciencescape.org) Innovation in the exploration of papers and authors.
- Scientific Journal Finder (http://www.sjfinder.com) Search engine, which recommends a list of journals based on title and abstract of scientific manuscript.
- Scizzle (http://www.myscizzle.com) Curator that automatically finds new and relevant research papers.
- Sparrho (http://www.sparrho.com) Personalised recommendation engine for science – allowing you to keep a bird's eye view on all things scientific.
- SSRN (http://www.ssrn.com/en) Multi-disciplinary online repository of scholarly research and related materials in social sciences.
- Wiki Journal Club (http://www.wikijournalclub.org/wiki/Main_Page) Open, user-reviewed summaries of the top studies in medical research.
- Zotero (https://www.zotero.org) Helps you collect, organize, cite, and share your research sources.

List 2. Reference managers

- ACS ChemWorx (https://hp.acschemworx.acs.org) Collaborative reference manager coupled with tools and services for authors.
- CitationStyles (http://editor.citationstyles.org) Find and edit CSL citation styles.
- CiteUlike (http://www.citeulike.org) Search, organise, and share scholarly papers.
- Colwiz (https://www.colwiz.com) Create citations and bibliography and set up your research groups on the cloud to share files and references.
- EndNote (http://endnote.com) Software tool for publishing and managing bibliographies, citations, and references
- Mendeley (http://www.mendeley.com) A unique platform comprising a social network, reference manager, article visualisation tools.
- Paperpile (https://paperpile.com) No-fuss reference management for the web (Google docs plugin).
- Papers (http://www.papersapp.com) Helps you collect and curate the research material that you're passionate about.

- Zotero (https://www.zotero.org) Helps you collect, organise, cite, and share your research sources

List 3. Article visualisation

- ACS ChemWorx (https://hp.acschemworx.acs.org) Collaborative reference manager coupled with tools and services for authors.
- Colwiz (https://www.colwiz.com) Create citations and bibliography and set up your research groups on the cloud to share files and references.
- eLife Lens (http://lens.elifesciences.org) Provides researchers, reviewers, authors, and readers with a novel way of looking at online content.
- Elsevier "Article of the Future" (http://lens.elifesciences.org) Aims to revolutionise the format of the academic papers in regard to presentation, content, and context.
- Interactive Science Publishing (http://lens.elifesciences.org) Allows authors to publish large datasets with original source data that can be viewed interactively by readers.
- Mendeley (http://www.mendeley.com) A platform comprising a social network, reference manager, article visualisation tools.
- Pubget (http://pubget.com) Search engine for life-science PDFs.
- PubReader (http://www.ncbi.nlm.nih.gov/pmc/about/pubreader) Alternative web presentation that offers another, more reader-friendly way to read literature in PMC and Bookshelf.
- ReadCube (https://www.readcube.com) Read, manage, & discover new literature.
- Utopia Docs (http://utopiadocs.com) Pdf reader that connects the static content of scientific articles to the dynamic world of online content.
- Wiley Anywhere Article (http://olabout.wiley.com/WileyCDA/Section/id-819787.html) Enhanced HTML article from Whiley publisher.
- Wiley Smart Article (http://eu.wiley.com/WileyCDA/Section/id-817760.html) Enhanced article tools for chemistry content in Whiley journals.

List 4. Electronic lab notebook

- Docollab (https://www.docollab.com) Helps you manage your scientific research, collaborate with your colleagues ,and publish your findings.
- elabftw (http://www.elabftw.net) Electromic lab notebook made by researchers, for researchers, with usability in mind.
- Evernote (https://evernote.com) A place to collect inspirational ideas, write meaningful words, and move your important projects forward.
- Findings App (http://findingsapp.com) Lab notebook app that allows you to organise your experiments, keep track of results, and manage your protocols.
- Hivebench (https://www.hivebench.com) Hosted numeric laboratory notebook tool to manage protocols, experiments, and share them with your team.
- Journal Lab (http://www.journallab.org) A community of scientists who share open summaries and peer review of published articles.
- LabArchives (http://www.labarchives.com) Web-based product to enable researchers to store, organize, and publish their research data.
- Labfolder (https://www.labfolder.com) Simple way to document your research and to organise your protocols and data.
- LabGuru (http://www.labguru.com) Supports day to day activities of a research group, from vision to execution, from knowledge to logistics.
- Laboratory Logbook (http://lablog.sourceforge.net) Document projects running in a lab and manage experimentally obtained data and its metadata.
- Sumatra (https://pypi.python.org/pypi/Sumatra) Automated electronic lab notebook for computational projects.

List 5. Protocol repository

- SciVee (http://www.scivee.tv) Science video sharing platform that includes protocols.
- Benchfly (http://www.benchfly.com) Video protocols and video platform for scientists.

- Benchling (https://benchling.com) Life science data management, and collaboration platform, where you can create, find, and discuss protocols.
- IPOL journal (http://www.ipol.im) Research journal of image processing and image analysis with algorithm descriptions and its source code.
- MyExperiment (http://www.myexperiment.org) Share workflows and in silico experiments.
- OpenWetWare (http://openwetware.org/wiki/Main_Pag) Share information, know-how, wisdom, and protocols among researchers working in biological fields.
- Pegasus (http://pegasus.isi.edu) Platform that helps workflow-based applications execute.
- Protocols (http://protocols.io) Crowdsourced universal protocol repository. Protocol online (http://www.protocol-online.org) A curator of protocols contributed by researchers around the world.
- Scientific Protocols (https://www.scientificprotocols.org) Share scientific protocols using the GitHub platform.

List 6. Work with code

- CDE Tool (http://www.pgbovine.net/cde.html) Deploy and run your Linux programs on other machines without any installation or configuration.
- Dexy (http://dexy.it) Helps your code to speak for itself with beautiful syntax highlighting.
- GitLab (https://about.gitlab.com) A git repository management, code reviews, issue tracking, and wiki's, all in one platform.
- iPython notebook (http://ipython.org/notebook.html) Interactive computational environment that allows code execution, text, mathematics, plots, and rich media.
- Kepler (https://kepler-project.org) Helps create, execute, and share models and analyses across scientific and engineering disciplines.
- Mercurial (http://mercurial.selenic.com) Control management tool with distributed source, giving each developer a local copy of the development history.
- nanoHUB (https://nanohub.org) Centralised platform for computational nanotechnology research, education, and collaboration.
- ROpenSci (http://ropensci.org) Packages that allow access to data repositories through the R statistical programming environment.
- Sweave (http://www.stat.uni-muenchen.de/~leisch/Sweave) Allows one to embed the R code for complete data analyses in latex documents
- System in Cloud (http://systemincloud.com) Platform, enabling clients to rapidly draw and execute data-flow diagram that run in cloud.

List 7. Find and share samples

- Addgene (http://www.addgene.org) Plasmid sharing platform.
- Antibody Registry (http://antibodyregistry.org) Gives researchers a way to universally identify antibodies used in in the course of their research.
- Biospecimens (http://biospecimens.cancer.gov) Platform for biospecimen-based research.
- Duke human heart (http://sites.duke.edu/dhhr) Repository for cardiovascular research scientists, including tissues samples and information.
- ELabInventory (https://www.elabinventory.com) Web-based laboratory inventory management system designed for life science research laboratories.
- Nanosupply (https://nanosupply.co) Platform facilitating sourcing and sharing of advanced materials for research and education.
- Sample of Science (https://www.sampleofscience.net) Peer-Sharing Platform for Scientific Samples.

List 8. Work with data

- Benchling (https://benchling.com) Life science data management and collaboration platform.
- Galaxy Project (http://galaxyproject.org) Web-based platform for data intensive biomedical research.

- GenePattern (http://www.broadinstitute.org/cancer/software/genepattern) Genomic analysis platform that provides access to hundreds of genomics tools.
- GenomeCompiler (http://www.genomecompiler.com) Genetic design platform allowing researchers to manipulate and design everything from single genes to entire genomes.
- Kaggle (https://www.kaggle.com) Platform for data prediction competitions.
- Kitware (http://www.kitware.com) Advanced software solutions and services for data intensive R&D
- mloss (http://mloss.org/software) Machine learning open source software.
- MyExperiment (http://www.myexperiment.org) Share workflows and in silico experiments.
- nanoHUB (https://nanohub.org) Centralised platform for computational nanotechnology research, education, and collaboration.
- Pegasus (http://pegasus.isi.edu) Platform that helps workflow-based applications execute.
- Plotly (https://plot.ly) Online tool to graph and share data.
- ROpenSci (http://ropensci.org) Packages that allow access to data repositories through the R statistical programming environment.
- Statcrunch (http://www.statcrunch.com) Provides data analysis via the Web.
- Sumatra (https://pypi.python.org/pypi/Sumatra) Automated electronic lab notebook for computational projects
- SURF In context (https://code.google.com/p/surf-incontext) Navigate through RDF relations in a smooth and understandable way.
- Sweave (http://www.stat.uni-muenchen.de/~leisch/Sweave) Allows one to embed the R code for complete data analyses in latex documents.
- Synapse (http://sagebase.org/synapse-overview) Platform to support open, collaborative data analysis for clear, reproducible science.
- System in Cloud (http://systemincloud.com) Platform, enabling clients to rapidly draw and execute data-flow diagram that run in cloud.
- Tableau (http://www.tableausoftware.com/products/trial) Easily and quickly analyse and present data and share insights.
- Taverna (http://www.taverna.org.uk) A suite of tools used to design and execute scientific workflows.
- VisTrails (http://www.vistrails.org/index.php/Main_Page) Scientific workflow and provenance management system that supports data exploration and visualisation.
- Wakari (https://www.wakari.io) Web-based python data analysis.
- WebPlotDigitizer (http://arohatgi.info/WebPlotDigitizer) Web based tool to extract data from plots, images, and maps.
- Wings (http://wings-workflows.org) Semantic workflow system that assists scientists with the design of computational experiments.
- Wolfram Alpha (http://www.wolframalpha.com) Web-based tools for scientific calculations.
- World Map (http://worldmap.harvard.edu) Allows users to explore, visualise, edit, collaborate with, and publish geospatial information.

List 9. Connect with experts and researchers

- Academia (http://www.academia.edu) A place to share and follow research and researchers.
- AcademicJoy (http://www.academicjoy.net) Share research ideas and story in research and innovation.
- Addgene (http://www.addgene.org) Connect with other researchers through this plasmid sharing platform.
- Benchling (https://benchling.com) Life science data management and collaboration platform.
- BiomedExperts (http://www.biomedexperts.com) Scientific social network to research, collaborate, and connect with researchers and medical experts worldwide.
- Biowebspin (http://www.biowebspin.com) Platform in life science worldwide to networks, work, look up information.

- Cureus (http://www.cureus.com) Free and open access to the medical journal and a place for physicians to build a digital CV.
- Direct2experts (http://direct2experts.org) A federated network of biomedical research expertise.
- Expertnet (http://expertnet.org) Helps you locate experts in Florida universities.
- GlobalEventList (http://www.globaleventslist.elsevier.com) A comprehensive directory of scientific events worldwide.
- Kaggle (https://www.kaggle.com) Connect with organisations in need of data prediction algorithms through open competitions for the best code.
- LabRoots (http://labroots.com) Social network for researchers.
- Linkedin (https://www.linkedin.com) Professional networking site for all.
- Loop (http://community.frontiersin.org) Open, cross-platform network for researchers and academics from the Frontiers journals.
- MalariaWorld (http://www.malariaworld.org) The world's scientific and social network for malaria professionals.
- Mendeley (http://www.mendeley.com) A unique platform comprising a social network, reference manager, article visualisation tools
- MyScienceWork (https://www.mysciencework.com) Diffuse scientific information and knowledge in a free and accessible way.
- nanoHUB (https://nanohub.org) Centralised platform for computational nanotechnology research, education, and collaboration.
- Open Science Framework (https://osf.io) Gathers a network of research documents, a version control system, and a collaboration software.
- Piirus (https://www.piirus.com) Helps researchers meet potential collaborators, build networks, and develop their core research.
- Research Connection (http://researchconnection.com) A searchable platform for research jobs and information.
- ResearchGate (https://www.researchgate.net) Social network for researchers.
- ScienceExchange (https://www.scienceexchange.com) Marketplace for shared lab instrumentations.
- SocialScienceSpace (http://www.socialsciencespace.com) Social network social scientists.
- Trelliscience (https://www.trelliscience.com) A digital platform that connects you to the rest of the scientific community, ran by the AAA.

List 10. Lab management

- Antibody Registry (http://antibodyregistry.org) Gives researchers a way to universally identify antibodies used in the course of their research.
- Asana (https://asana.com) Keeps your team organised, connected, and focused on results.
- Biocompare (http://www.biocompare.com) Find products, read reviews, and hear about the latest technological developments.
- ELabInventory (ttps://www.elabinventory.com) Web-based laboratory inventory management system designed for life science research laboratories.
- LabCritics (http://www.labcritics.com) Provides researchers with a trust-able source of lab equipment reviews and comparisons.
- LabGuru (http://www.labguru.com) Supports day to day activities of a research group, from vision to execution, from knowledge to logistics.
- Life technologies Lab Management Tool (http://www.lifetechnologies.com) Management tool for lab equipment and services.
- Open Science Framework (https://osf.io) Gathers a network of research documents, a version control system, and a collaboration software.
- Quartzy (https://www.quartzy.com) A free and easy way to manage your lab.
- Quip (https://quip.com) Combines chat, documents, spreadsheets, checklist, and more to collaborate on any device.

- StrainControl (http://www.straincontrol.com) Lab management tools that allows you to organise strains, plasmids, oligos, antibodies, chemicals, and inventory.
- Synapse (http://sagebase.org/synapse-overview) Platform to support open, collaborative data analysis for clear, reproducible science.

List 11. Outsourcing experiments

- Emerald Cloud Lab (http://emeraldcloudlab.com) A web-based life sciences lab, developed by scientists for scientists.
- ScienceExchange (https://www.scienceexchange.com) Marketplace for shared lab instrumentations.
- Transcriptic (https://www.transcriptic.com) A remote, on-demand robotic life science research lab with no hardware to buy or software to install.

List 12. Paper repositories

- ArXiv (http://arxiv.org) E-prints in Physics, Mathematics, Computer Science, Quantitative Biology, Quantitative Finance and Statistics.
- biorXiv (http://biorxiv.org) The preprint server for Biology.
- F1000 (http://f1000.com) Leading biomedical experts helping scientists to discover, discuss, and publish research.
- Figshare (http://figshare.com) Manage your research in the cloud and control who you share it with or make it publicly available and citable.
- Peer Evaluation (http://www.peerevaluation.org) Open repository for data, papers, media coupled with an open review and discussion platform.
- Peerage of Science (https://www.peerageofscience.org) Pre-publication peer review and publishing for scientific articles.
- PeerJ PrePrints (https://peerj.com/preprints) Pre-print repository for the biological and medical Sciences.
- SlideShare (http://www.slideshare.net) Community for sharing presentations and other professional content.
- Zenodo (https://zenodo.org) A home for the long-tail of science, enabling researchers to share and preserve any research output.

List 13. Open access platforms

- eLife (https://www.zotero.org) Open access to the most promising advances in science.
- F1000 (https://www.zotero.org) Leading biomedical experts helping scientists to discover, discuss, and publish research.
- GigaScience (http://www.gigasciencejournal.com) Online open-access open-data journal that publishes 'big-data' studies from the life and biomedical sciences.
- Limn (http://limn.it) Free journal that outlines contemporary problems.
- PeerJ (https://peerj.com) Open access pre-print and publishing of life science research with annotation.
- Cureus (http://www.cureus.com) Free and open access to the medical journal and a place for physicians to build a digital CV.
- ScienceOpen (https://www.scienceopen.com) Freely accessible research network to share and evaluate scientific information.
- The Winnower (https://thewinnower.com) Open access online science publishing platform that employs open post-publication peer review.

List 14. Collaborative writing tools

- ASCII doctor (http://asciidoctor.org) Text processor & publishing toolchain for converting AsciiDoc to HTML5, DocBook & more.
- Atlas (http://asciidoctor.org) Write, collaborate, design, and publish on a single platform.

- Authorea (https://www.authorea.com) Platform to write scientific, academic, and technical documents in collaboration.
- Draft (https://www.authorea.com) Version control and collaboration to improve your writing.
- Fidus Writer (http://fiduswriter.org) Online collaborative editor especially made for academics who need to use citations and/or formulas.
- Penflip (https://www.penflip.com) Collaborative writing and version control.
- SciGit (https://www.scigit.com) Change tracking solution for effortless collaborative writing.
- ShareLaTex (https://www.sharelatex.com) Collaborative on-line editor for for Maths or Sciences.
- WriteLaTex (https://www.writelatex.com) Online collaborative LaTeX editor.
- Stackedit (https://stackedit.io) Markdown editor based on PageDown, the Markdown library used by Stack Overflow.
- Typewrite (https://typewrite.io) A simple, real-time collaborative writing environment.
- Poetica (https://poetica.com) Get clear feedback, wherever you're writing.
- Quip (https://quip.com) Combines chat, documents, spreadsheets, checklist, and more to collaborate on any device.

List 15. Support to publication

- Collage Authoring Environment (https://collage.elsevier.com) Framework for collaborative preparation and publication of so-called executable papers.
- Exec&Share (http://www.execandshare.org/CompanionSite) Openly share the code and data that underlie your research publications.
- Google Charts (https://developers.google.com/chart) Create live and interactive charts in your browser.
- RunMyCode (http://www.runmycode.org) Openly share the code and data that underlie your research publications.
- ORCID (http://orcid.org) Provides a persistent digital identifier that distinguishes you from every other researcher.

List 16. Peer-review

- Academic Karma (http://academickarma.org) Peer review and get peer reviewed faster.
- F1000 (http://f1000.com) Leading biomedical experts helping scientists to discover, discuss, and publish research.
- Hypothes.is (http://hypothes.is) Sentence-level peer-review to provide commentary, references, and insight on top of online content.
- Journal Review (https://www.journalreview.org) Rate and review published medical journal articles.
- Libre (http://www.liberatingresearch.org) Participative reviewing platform.
- Paper Critics (http://papercritics.com) Review platform for research publications (Mendeley plugin).
- Peerage of Science (https://www.peerageofscience.org) Pre-publication peer review and publishing for scientific articles.
- PeerJ (https://peerj.com) Open access pre-print and publishing of life science research with annotation.
- PubPeer (https://pubpeer.com) Search for publications and provide feedback and/or start a conversation anonymously.
- Publons (https://publons.com) Record, showcase, and verify all your peer review activity.
- Pubmed Commons (http://www.ncbi.nlm.nih.gov/pubmedcommons) Share opinions and information about scientific publications in PubMed.
- Rubriq (http://www.rubriq.com) Provides an independent peer review prior to submission.
- ScienceOpen (https://www.scienceopen.com) Freely accessible research network to share and evaluate scientific information.

- Wiki Journal Club (http://www.wikijournalclub.org/wiki/Main_Page) Open, user-reviewed summaries of the top studies in medical research.
- The Winnower (https://thewinnower.com) Open access online science publishing platform that employs open post-publication peer review.

List 17. Outreach

- AcademicJoy (http://www.academicjoy.net) Sharing research ideas and story in research and innovation.
- AcaWiki (http://acawiki.org) Summarising academia and quasi-academia, one document at a time.
- DrawScience (http://drawscience.blogspot.com) Take science articles, make pictures.
- I Am Scientist (http://imascientist.org.uk) A science outreach education and engagement activity.
- nanoHUB (https://nanohub.org) Centralised platform for computational nanotechnology research, education, and collaboration.
- Publiscize (http://www.publiscize.com) Empowering scientists to free science and make their research available to everyone.
- ScienceGist (http://www.sciencegist.com) Simplified summaries of scientific papers.
- SciVee (http://www.scivee.tv) Science video sharing platform.
- SciWorthy (http://sciworthy.com) A science news site for the everyday person to better understand science.
- Useful Science (http://www.usefulscience.org) Summaries of the latest science useful in life.

List 18. Citizen science

- Folding@home (http://www.usefulscience.org) Distributed computing project which studies protein folding, misfolding, aggregation, and related diseases.
- Kaggle (https://www.kaggle.com) Platform for data prediction competitions.
- Project Noah (http://www.projectnoah.org) Explore and document wildlife on this citizen scientists platform.
- SciStarter (http://scistarter.com) Find, join, and contribute to science through recreational activities and citizen science research projects.
- SETI@home (http://setiathome.ssl.berkeley.edu) Put your CPU to work to help detect intelligent life outside Earth.
- Zooniverse (https://www.zooniverse.org) Citizen science projects using the efforts and ability of volunteers to help scientists and researchers.

List 19. Altmetrics

- Altmetric (http://www.altmetric.com) Tracks what people are saying about papers online on behalf of publishers, authors, libraries, and institutions.
- ImpactStory (https://impactstory.org) Share the full story of your research impact.
- PLOS Article-Level Metrics (http://article-level-metrics.plos.org) A suite of established metrics that measure the overall performance and reach of research articles.
- PlumAnalytics (http://www.plumanalytics.com) Research altmetric service tracking more than 20 different types of artifacts.
- Publons (https://publons.com) Record, showcase, and verify all your peer review activity.

List 20. Fundraising/Grant-writing

- Grant Forward (https://www.grantforward.com/index) Search engine for research grants.
- Pivot COS (http://pivot.cos.com) A database which includes funding opportunities from all disciplines.
- Writefull (http://writefullapp.com) Provides feedback on your writing using data from the Google Books database.

List 21. Crowdfunding

- Experiment (https://experiment.com) Crowdfunding Platform for Scientific Research.
- My Projects (http://myprojects.cancerresearchuk.org) Donate to the research work that means the most to you.
- Petridish (http://www.petridish.org) Fund science & explore the world with renowned researchers.
- SciFlies (http://www.petridish.org) Allows anyone, anywhere, to directly support research they care about.
- Consano (https://www.consano.org) Research crowdfunding site to directly support innovative medical research that matters to you

List 22. Find and share data and code

- BioLINCC (https://biolincc.nhlbi.nih.gov/home) Clinical specimen database.
- ContentMine (http://contentmine.org) Uses machines to liberate 100,000,000 facts from the scientific literature.
- DataBank (http://databank.worldbank.org/data/home.aspx) Analysis and visualisation tool that contains collections of time series data on a variety of topics.
- DataCite (http://www.datacite.org) Establish easier access to research data by providing persistent identifiers for data.
- DataHub (http://datahub.io) Publish or register datasets, create, and manage groups and communities
- Dataverse Network (http://thedata.org)Harvard-based tool to share, cite, reuse, and archive research data.
- Dryad (http://datadryad.org) Data repository for any files associated with any published article in the sciences or medicine.
- Figshare (http://figshare.com) Manage your research in the cloud and control who you share it with or make it publicly available and citable.
- GenBank (http://www.ncbi.nlm.nih.gov/genbank) Gene sequence database provided by the National Center for Biotechnology Information.
- GitHub (https://github.com) Online software project hosting using the Git revision control system.
- Nowomics (http://nowomics.com) Follow genes, proteins, and processes to keep up with the latest papers and data relevant to your research.
- Open Science Framework (https://osf.io) Gathers a network of research documents, a version control system, and a collaboration software.
- Peer Evaluation (http://www.peerevaluation.org) Open repository for data, papers, media coupled with an open review and discussion platform.
- Quip (https://quip.com) Combines chat, documents, spreadsheets, checklist, and more to collaborate on any device.
- re3data (http://www.re3data.org) Global registry of research data repositories.
- Research Compendia (http://researchcompendia.org) Tools for researchers to connect their data, code and computational methods to their published research.
- SlideShare (http://researchcompendia.org) Community for sharing presentations and other professional content.
- Socialsci (https://www.socialsci.com) Help researchers collect data for their surveys and experiments.
- Zenodo (https://zenodo.org) A home for the long-tail of science, enabling researchers to share and preserve any research output.

List 23. Research & Development platforms

- Innocentive (http://www.innocentive.com) Open innovation problem solving.
- IdeaConnection (http://www.ideaconnection.com) Idea marketplace and problem solving.

- Presans (http://www.presans.com) Help access worldwide intelligence and knowledge.
- Innoget (http://www.innoget.com) Marketplace for technologies and knowledge.
- One Billion Minds (http://www.onebillionminds.com) Connects people to striking projects of change.
- NineSigma (http://www.ninesigma.com) Open innovation services provider.
- Ideaken (http://www.ideaken.com) Collaborate to innovate.
- Innovation-community (https://www.innovation-community.net) – Community of innovators, creators, designers. and thinkers.

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The report analyses the potential impact of a transition towards Open Science on the stakeholders of the research ecosystem. The following findings are discussed.

- Innovative digital tools that facilitate communication, collaboration, and the data analysis will enable Open Science practices.
- All stakeholders of the research ecosystem will benefit from Open Science, although it will change work habits and business models.
- Digital platforms will facilitate innovation by streamlining all phases of the innovation process, from the generation of ideas to experimental work and fundraising.
- Citizens will become new players of the research ecosystem. They will shape science policies and contribute to scientific research through citizen science actions and by funding researchers.
- Digital science start-ups will shape the future of Open Science and innovate in the exploitation of the flow of information made publicly available with the advent of Open Science.
- The EU can accelerate the transition towards Open Science thanks to its unique position as funder and policy maker. A three-step program is suggested that will: 1) support the on-going transformation; 2) make systemic change to open the way to fully implemented Open Science; and 3) unlock the societal and economic value of Open Science.

Studies and reports

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