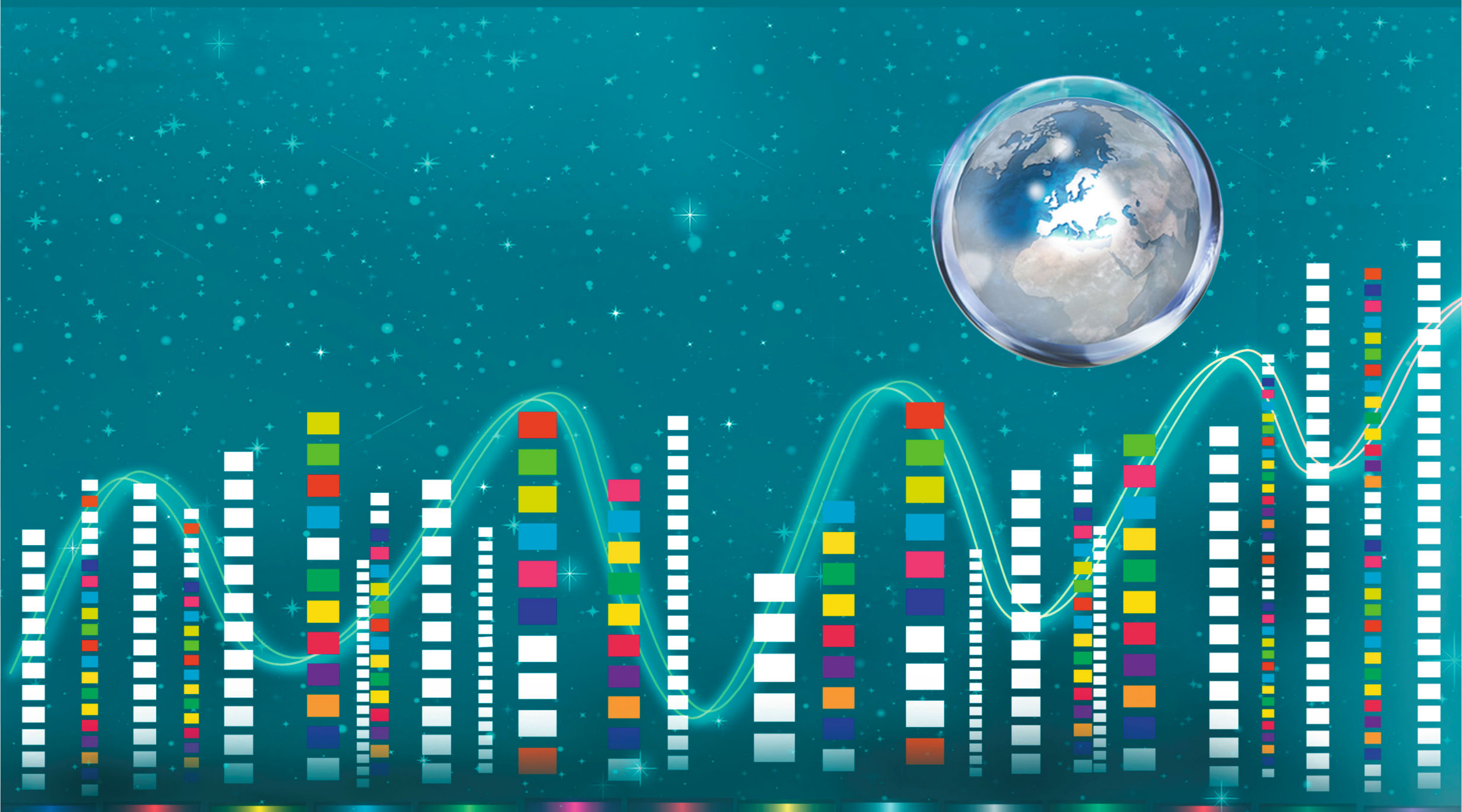
European Commission

Perspectives on the future of Open Science

Effects of global variation in open science practices on the European research system



Research and Innovation

Perspectives on the future of Open Science. Effects of global variation in open science practices on the European research system

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EUROPEAN COMMISSION

Perspectives on the future of Open Science

Effects of global variation in open science practices on the European research system

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Directorate-General for Research and Innovation
2021 Europe in a changing world. Inclusive, innovative and reflective societies

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SUMMARY

Open science proposes a fundamental systemic change in the way research is conducted, shared and evaluated. Through increasing the availability and accessibility of research results and involving societal actors in the research process, the open science movement aims to make the research process more efficient, transparent and responsive to global societal challenges.

The European Commission has long been a front-runner in adopting open science as a policy target. However, its opportunities to take open science further and the consequences of doing so depend on the behaviour of other countries. After all, science is an international enterprise and realising open science requires changing many internationally accepted scientific practices and routines.

An uneven adoption of open science practices across the world involves serious risks, such as limitations to the career opportunities of researchers, high costs of open science implementation and free riding behaviour by countries profiting from the increased access to research without reciprocating that openness. Against this background, this foresight study considers how different levels and means of open science policy implementation in the two countries with the highest R&D investments (the United States and China) could affect the European opportunities to realise open science and the consequences for the European science system. The study looks at three dimensions of open science: open access, open data and open collaboration. It starts with a literature review of the most important drivers and barriers to open science and current developments in the three regions under scrutiny (US, China and the European Union) that enable open science. It then looks to the future and postulates four different scenarios for 2030 to explore the future realisation of open science under different geographical circumstances.

1 Drivers and barriers

For this study, we looked at 11 drivers of and 8 barriers to open science practices as identified by the European Commission for the purpose of this study. We have clustered these drivers, presented on page 12 of the report, in three groups. Each cluster represents different mechanisms of stimulating open science practices:

- creating awareness and providing information on the opportunities and advantages of open science;
- incentives and disincentives for researchers;
- developing the necessary framework conditions: infrastructures, policies and skills development.

We review the relevance and importance of these clusters for each aspect of open science and then explore differences in the extent to which open science policies have been developed in China, the US and the European Union.

Open access

More and more research funders require open access publication of results. The diversity of available publication routes and the variety of funders' and publishers' open access policies create legal and practical uncertainties, though. More awareness is needed both of the technical aspects and of the benefits of publishing this way. Researchers generally regard open access as a positive phenomenon. However, researchers experience several barriers on their way to open access publishing, in addition to legal uncertainties and complex regulations. Traditional recognition and reward systems in science still consider publishing in high-impact journals of great importance. Many research councils now remove financial disincentives by providing coverage of article processing charges. Several kinds of infrastructures have been developed for the different routes to open access

publishing, including: online platforms of open access journals and publishers and large institutional and subject repositories. Furthermore platforms have been developed that support publication and provide peer review processes – often open peer review processes.

Open data

There is still a lack of awareness among many researchers on the possibilities and benefits of open data. It can be expected that current initiatives and requirements by funders, journals and academic organisations will contribute to the necessary awareness. There is increasing evidence that sharing research data is not only beneficial for society and the economy, but also for researchers themselves. This may further stimulate open data. Journals and research funders are the main actors who (can) provide incentives for open data. Simultaneously, they constitute the key building blocks of the current reward system of science that discourages researchers to openly share research data. One universal barrier for open data is that it simply takes time for authors, editors, peer reviewers and editorial support staff to enable it. Other barriers to open data are field-specific. For instance, concerns about being outcompeted, about misuse of data and with regard to privacy issues. The development of open data can be strongly driven by the integration of open science in infrastructures and assistance with tools and services. The adaptation of university curricula, education and training are needed to overcome the lack of skills.

Open collaboration

There is evidence that open collaboration generates career benefits for academic researchers. However, many researchers hesitate to engage in open collaboration. More evidence of the benefits of open collaboration for researchers could make a big difference. An increasing awareness of the benefits of open collaboration will also encourage both policy-makers and research funders to further stimulate and reward open collaboration. The experiences with open collaboration vary strongly across disciplines. Researchers experience a particularly strong barrier to collaborate with industry, because industry often poses restrictions on the way researchers can communicate and share research results. Conditions and criteria formulated by research councils and other funding organisations can strongly influence open collaboration, as the European Framework Programmes demonstrate. Due to the complications of working with the non-academic partners discussed above, a lack of skills can be a barrier to open collaboration, in particular when working with public actors or citizens that are unfamiliar with scientific routines. This can be overcome by training researchers in communication and collaboration skills and the adaptation of university.

China

The impressive growth of Chinese R&D capacity over the past decades has come with public policies that stimulate university-industry collaboration. These have resulted in a high share of private funding. The Chinese government has implemented open access policies but China is still lagging slightly behind the US and the European Union. It is expected that open access offers a way to serve China's domestic needs while maintaining international visibility. While open access through repositories ('green route') has been mandated, Chinese researchers seem to have a preference for open access publications via the gold route (in open access journals). Open data policies are heavily centralised: all scientific data generated in China must be submitted to government-sanctioned data centres before appearing in publications. There are indications that China may change its evaluation policies to rely less on bibliometric indicators, which may further stimulate open science.

United States

Many initiatives to promote open access and open data have originated in the United States. Since 2013, the US federal government requires public online availability of results of publicly funded research within 12 months of publication in a journal. Since 2017, all federal agencies have plans to increase public access to scholarly publications and digital data. A relatively high share of open access articles from the US is solely available through an institutional or subject repository (green route). Institutional mandates play a much larger role in the US than in China. The country has by far the largest number of data repositories. In the area of open collaboration, there are some initiatives to stimulate collaboration with a variety of stakeholders. The number of collaborative initiatives between higher education institutes and private parties in the US is comparable to the averages of the OECD and EU27.

European Union

The European Commission's open science policy addresses the openness of research data and results. Furthermore, it entails the development of both physical and social structures that will enable researchers to comply with open science requirements. In open access, the European Union is on par with the US. Hybrid open access plays a larger role in Europe than in the US and China, suggesting a bigger role for read & publish deals. Two central pieces of infrastructure that have been developed are Open Research Europe (for publications) and the European Open Science Cloud (for research data). The R&D Framework programmes have long fostered collaboration between research, business and government sectors and have (more recently) promoted citizen science. Compared to China and the United States, the European Union focuses more on sharing intermediate research results, enabling reuse of data, and recognising and rewarding open science practices.

2 Four scenarios and possible European policy responses

Two factors that may influence the development of open science practices in China, the US and the European Union are the degree of geopolitical tension and the dominant interaction and coordination mechanisms in society. Therefore, we may expect that the extent to which coordination mechanisms in science and broader society are oriented towards solving societal challenges influences the opportunities for open science practices as well. We will draft four scenarios on the possible future development of open science practices in China and the US by combining these two influential factors. Each scenario is named after the strategic aim of the science policy in this particular scenario: Defence, Growth, Missions and Prosperity.

Defence

In this scenario, the geopolitical tension between the US, Europe and China is high and competition is the principal mechanism of interaction and coordination in society. Publicly funded science will primarily serve business interests. Competition between universities remains fierce. This is not a climate conducive to open access, open data and open collaboration. Traditional publishers and their journals remain important players in the US and limit open access opportunities by demanding high fees and imposing long embargo periods. Large academic publishers and big tech companies provide services to store, curate and document data – but they do so at high prices. China continues to focus on its own knowledge needs, hidden from view behind visa requirements and internet controls. Consequently, Chinese publications and data become less accessible to Europe.

Neither China nor the US invest in policies to implement open science, because the costs are high. Incentives to protect national security interests and to demonstrate one's own scientific excellence prevail. Open science remains a movement pushed by members of the academic community, leading to scattered initiatives such as alternative publication platforms. This will not lead to large changes in publication and collaboration practices.

In this scenario, Europe has the choice to either massively step up its efforts and investments in its own publishing and data sharing – to keep up with the private services developed mainly in the US – or compromise on open access and open data. Continuing with current open access and open data ambitions means that European science will be progressively disadvantaged due to the high costs and lack of reciprocity in access. However, continuing on its path may benefit the quality of European science, as more feedback is received. To counterweigh the US and China and work on open science in this scenario, EU member states could be stimulated to join forces and reinforce EU cooperation in science, particularly in the areas of defence and business interests. Such strong European cooperation could also lower the costs of open access and open data.

Growth

In this scenario the geopolitical situation is harmonious, but competition remains the principal interaction and coordination mechanism in science and society. China is gradually integrated in the global science system with common organisational principles.

Academic publishers maintain their grip on the publication and distribution of research papers and invest in the development of data services. Consequently, gold or hybrid open access publishing are utilised most. Moreover, businesses develop and provide data services. However, governments and research funders push to decrease the costs of these open access and data services.

There is progress on open science in China and the US, but this is generated bottom-up and only as far as it can be organised together with business and business interests. Both governments, research funders and actors within the academic community invest primarily in creating awareness about open science practices. Due to the predominance of business interests and competition in science, no real progress is made on incentivising researchers to practice open science or creating worldwide, integrated infrastructures for the sharing of data and publications. Consequently, open science remains focused on cooperation with business. It is therefore mainly about access to scientific articles and data from the medical, technical and natural sciences.

With economic growth as its overriding policy goal, open science in Europe will most likely be geared to opening up science to business interests. Sharing research results and data intensively with these stakeholders will help Europe to create a competitive advantage. However, competitive interests form a strong barrier to dispersing research results in the public domain. Competition fosters creativity and invention, but hampers openness. The risk of a brain drain from Europe is high in this scenario. This is due to the fact that competition drives up the amounts of funding needed to retain top-class researchers in the competition with the US and China.

Missions

In this world of high geopolitical tension, governments increasingly seize the initiative to address a number of pressing issues and grand societal challenges. Coordination rather than competition becomes the dominant organisational paradigm. As part of mission-oriented science and innovation policies, a transition to open science is pursued to speed up research and increase the efficiency and effectiveness of public research spending. However, this pursuit is obstructed by a lack of internationally shared standards and frameworks.

Strides towards open access, open data and open collaboration are made that remain within three separate regional blocks. Collaboration takes place primarily within regional borders and infrastructure for sharing data and publications is developed on a regional level. It is likely that strong links between European and American repositories and research data platforms remain, while China draws the short end of the bargain. Progress on open science is likely concentrated in relatively harmless fields, as both the US and China guard against the spilling over of sensitive knowledge. Because the research community is very active and influential, supported by governments and funders, diamond open access soars in this scenario. This means that the role of publisher-owned (traditional and gold) journals diminishes. Open data services are developed within the public sphere. While collaboration is predominantly local, there is a significant rise in citizen engagement, primarily in the US.

In this scenario, European governments will try to balance openness with restraint, for fear of giving too much knowledge and technologies away and being dominated – economically and politically – by China. Nevertheless, the resolve to invest in joint programming and research collaboration is high and science gets a massive boost. Substantial public investments in open science infrastructures for the curation and exchange of publications and data and other research intermediaries help to speed up research processes. In addition, they help to monitor and certify their quality and integrity. As different regions may apply different solutions for data and publication sharing, it is important that Europe implements good mechanisms for scientific quality control.

Prosperity

This policy environment, with low geopolitical tension and a focus on solving global societal challenges, is optimal for the development of open science. All drivers stimulate open science to flourish.

Governments and research funders who demand open access publishing have become a worldwide standard. Open access diversifies – from scientific papers to books and other forms of output in various languages. Digital platforms managed by the research community have become central in improving accessibility to both publications and data. These infrastructures that enable the sharing of data and publications are increasingly interoperable. In addition, publication processes and rules are growing uniform. Frequent and intensive collaboration with non-academic partners has become a self-evident part of work for most academic researchers. Especially in the US, citizen science has become mainstream.

While Europe profits from the radically open research climate that makes its research more productive, efficient and of a higher quality, it is vulnerable to losing its research capacity to China and the US. To remain attractive to researchers in this scenario, Europe must develop a distinctive profile. This implies maintaining close connections to global networks, fostering absorptive capacities (through open science practices and researcher mobility) and developing key competencies in areas of strategic importance. Open science policies that stimulate open collaboration can help to nurture a sustainable specialised ecosystem in Europe. As in the previous scenario, Europe profits from an increase in feedback on scientific results, which makes science more productive and of better quality.

3 General policy recommendations

Because the costs and benefits of an open science policy differ across the four scenarios, we cannot advice on a single robust policy strategy that is preferable in each scenario. We conclude this report with a couple of policy directions that are bound to be productive in most of the scenarios:

- Creation of a distinctive profile of European science, based on European values.
- Coordination of investments in data standardisation and data curation capacity.
- Investment in quality control, to ascertain the quality of data or research findings from other regions.
- Further development and promotion of new ways to incentivise and reward researchers to contribute to open science.
- Stimulation of open collaboration with a diversity of non-scientific partners, both private and public.

As a closing remark, we advise to look beyond the two countries addressed in the current study, and consider the value of cooperation with the global south in the further development of Europe's open science strategy.

INTRODUCTION

Open science is "A new approach to the scientific process based on cooperative work and new ways of diffusing knowledge by using digital technologies and new collaborative tools" (European Commission, 2016a, p.33). Open science policies aim to increase the public availability and accessibility of research results, and do so as early as possible during the research process (Foster, n.d.). The goal of this sharing is not only to make the diffusion of knowledge more efficient, but also to promote and facilitate collaboration within the academic community and with actors outside of it. Open science policies mainly address open access to scientific publications, the open sharing of research data and promoted collaboration with non-scientists and public engagement.

Open science is assumed to have several benefits (OECD, 2015). First of all, open science is expected to make research more efficient and speed up scientific enquiry to the benefit of society, for example by reducing duplication. Second, it is assumed to increase the reliability of research and its outcomes because it enables transparent scrutiny and evaluation – improving both quality and public trust in science. Third, it is likely to make science more responsive to public needs and societal challenges, as it makes research processes more accessible to groups outside of the academic community. The recent response of scientists to the COVID-19 pandemic has demonstrated how open science can accelerate the achievement of scientific solutions for a global challenge (OECD, 2020b, UNESCO, 2020).

Thus, the ambitions for and expectations of open science are high. In enabling more open sharing, it can contribute to developing scientific knowledge as a global common good that is shared reciprocally and to the universal collective benefit (UNESCO, 2021). UNESCO has developed a recommendation to aid the international community in developing equitable and inclusive open science policies. The upcoming signing (November 2021) of this recommendation by its Member States is a clear indication of international momentum for open science.

1 Purpose of the study

Against this background the European Commission has asked the Rathenau Instituut to carry out a foresight study to consider how the adoption of various open science policies in China and the United States affect the European science system. Opening up science has many benefits, but requires a systemic change in the way research is conducted, shared and evaluated. Realising open science is not just a question of new and interoperable infrastructures for sharing publications and data, but also requires significant changes in the way we evaluate and reward researchers' achievements and the skills we teach them. It also changes the services demanded from publishers and academic libraries.

Realising such a systemic change involves an internationally coordinated effort of researchers, universities, research institutes, publishers, research councils and policy makers. The European Commission has been a front-runner in adopting open science as a policy target. Over the last decade, open science policies have become part and parcel of the European R&I Framework Programmes. The Commission is one of the initiators of Plan S. The ambitions are high, but the possibilities to create a more open science, and the way this affects the European science system, may depend on the extent to which other regions of the world implement similar ambitions. What if journal impact factors remain important for a career in the United States, or China profits heavily from the increased availability of open data without reciprocation?

Therefore, we look at the (expected) development of open science in the two countries with the highest scientific output, China and the United States, and explore the likely effects of these developments on the science system of the European Union. Due to the focus of our assignment, we leave important open science developments in the global south, particularly South America, and the question on how to realise the open science ambitions in a globally inclusive manner, out of our analysis. In our conclusion, we do reflect briefly on how our scenarios align with these open science ambitions.

Where the original assignment was to look at the regions of Asia and North America, we soon discovered that there is too much variety in open science practices between countries to make a generalisation on the regional level. As such, we focus on China and the US. As large funders and producers of scientific research, developments in these countries may heavily influence the position of European scientific research. We made an exception for the European Union, where we focus on *European* open science policies and practices. Although there are differences between member states in the approach and extent of open science policies, the European Commission plays an important role in coordinating and fostering open science policies (European Commission, 2017).

We focused our analysis on the three most common dimensions of open science: open access, open data and open collaboration. Two definitions of 'open' interact in these three dimensions: the openness of the results of scientific endeavours, and the openness of the research process itself to parties outside of the academic community. Both are important parts of open science, but openness of the research process does not necessarily mean openness of its results.

The report starts by reviewing the most important drivers of and barriers to the adoption of open science practices and how these drivers and barriers are currently employed in the three regions under scrutiny, China, the US and the European Union. Using a scenario approach, it then explores how open science policies in these regions might develop under various circumstances (what drivers are used and barriers resolved) – and how this affects the science system of the European Union. As such, the scenarios provide a variety of building blocks to develop future European open science policies in a way that makes its scientists flourish.

2 Questions guiding the foresight study

In line with the European Commission's request, this foresight study was guided by three questions:

- How does the combination of drivers for and barriers to the adoption of open science practices vary across three regions (Europe, the United States, China)?
- What are plausible future scenarios in terms of a combination of drivers and barriers influencing open sciences practices in three dimensions (Open Access, Open Data and Open to Society) in these three regions?
- What are expected positive and negative effects of these scenarios on quality and pathways to societal impact of science in Europe?

Each question corresponds to one chapter in the report:

- The first chapter: A review of eleven drivers and eight barriers that affect the adoption of open science practices and their impact in the three regions under consideration, Europe, the United States and China.
- The second chapter: The construction of four scenarios that represent four different but plausible futures for open science in the United States and China.
- The third chapter: European policy responses to each of the four scenarios of developments outside Europe and their effects on the productivity, quality and impact of European science.

3 Method

We started our analysis with a review of the different drivers and barriers as defined by the European Commission for this assignment for each dimension of open science: open access, open data and open collaboration. We performed a quick scan of the available literature to identify, for each dimension, the most important drivers and barriers. Due to time constraints inherent to the assignment, the review is not exhaustive, and focuses on drivers and barriers as experienced at the level of individual researchers.

Our literature scan also helped us get a global overview of the open science policies in China, the United States and the European Union. To inform the development of scenarios, we also collected data on a few aspects of the Chinese, American and European science system: total R&D investments, share of open access publications and private R&D investments.

Based on the information on relevant drivers and barriers and national/regional policies, we developed four scenarios about the adoption of open science policies in China and the United States. We used two dimensions to devise the scenarios:

- **Amount of geopolitical tension**: because the focus of this study is on the interaction between the European, American and Chinese science system, we chose the degree of geopolitical tension as one of the dimensions, distinguishing between a future with harmonious international relationships and a future with international conflict.
- **Dominant interaction and coordination mechanisms**: the other dimension we chose is that of the dominant coordination mechanisms in society at large and in science in particular. We distinguish between competition and the use of the market mechanism on the one hand, and coordination through hierarchies and networks, in particular with an eye on achieving collective public goals, on the other hand. We chose this dimension because improving science's contribution to collective public goals is inherent to the open science ambitions. Therefore, the extent to which coordination is explicitly geared toward those collective public goals will influence the possibilities for open science to flourish.

Crossing these two dimensions leads to four scenarios. For each scenario, we used the knowledge gathered about the drivers and barriers and open science policies to predict to what extent China and the US would remove barriers and implement drivers in order to provide an open science infrastructure, provide incentives for open science practices and create awareness and training opportunities for researchers. Finally, we used our knowledge of European open science and general science policies to reflect on the implications of different Chinese and American policies and what course of action to take. A draft of the report has been reviewed by prof. Sabina Leonelli and prof. Geoffrey Bolton. The responsibility for the contents of this report rests solely with the authors.

4 Drivers and barriers

The starting point for our scenario analysis is the evaluation of the effects of a number of drivers and barriers for open science, as suggested to us by the European Commission (see box below).

Drivers:

1. Giving credit to open science practices (for instance as additional points in research proposal evaluation and/or in researcher career assessment).
2. Evidence of benefits for researchers (team work, cooperation, internationalisation, et cetera).
3. Integration of open science in infrastructures and assisted by tools and services.
4. Increasing awareness of open science practices and benefits.
5. Education and training available on open science practices.
6. Financial incentives by funders for open science practices.
7. Incentives to publish in open access on online platforms.
8. Incentives to reuse research outputs.
9. Adaptation of university curricula (for open science).
10. Engagement with citizen science.
11. Fostering open peer review.

Barriers:

1. Lack of credit or acknowledgement.
2. Concerns about being outcompeted.
3. (Uncertainty about) legal constraints (for instance copyright law, licensing restrictions et cetera).
4. Cost and time of sharing data or of engaging with a broad spectrum of stakeholders.
5. Concerns about misuse of data.
6. Lack of skills (for instance data stewardship).
7. Privacy issues.
8. Uncertainty about socio-economic benefits of open science.

To make our analysis manageable, we have clustered these 19 drivers and barriers into three groups. The first group assembles those factors that affect the knowledge and information that researchers have about open science. The second group contains the factors that act as an incentive or a disincentive for researchers to engage in open science. The third group consists of the factors that affect the structural aspects and framework conditions under which academic research is being performed and that may or may not facilitate open science. The three groups are presented in the text box below (also for reference when reading the rest of this report).

Awareness, information and knowledge

- Providing awareness / training:

  D4. Increasing awareness of open science practices and benefits.

- Removing informational barriers:

  B3. (Uncertainty about) legal constraints.
  B8. Uncertainty about socio-economic benefits of open science.

- Clarifying indirect / secondary effects:

  D2. Evidence of benefits for researchers.

Incentives and Disincentives for researchers

- Providing incentives: credit / funding

  D1. Giving credit to open science practices.
  D6. Financial incentives by funders for open science practices.
  D7. Incentives to publish in open access on online platforms.
  D8. Incentives to reuse research outputs.

- Removing disincentives / costs:

  B1. Lack of credit or acknowledgement
  B4. Cost and time of sharing data and of engaging with a broad spectrum of stakeholders.

- Dealing with concerns / uncertainties:

  B2. Concerns about being outcompeted.
  B5. Concerns about misuse of data.
  B7. Privacy issues.

Framework conditions, system adaptations and investment in skills

- Providing infrastructure:

  D3. Integration of open science in infrastructures and assisted by tools and services.

- Providing policy:

  D9. Adaptation of university curricula.
  D10. Engagement with citizen science.
  D11. Fostering open peer review.

- Developing necessary skills:

  D5. Education and training available on open science practices.
  B6. Lack of skills.

OPEN SCIENCE: A REVIEW OF DRIVERS AND BARRIERS

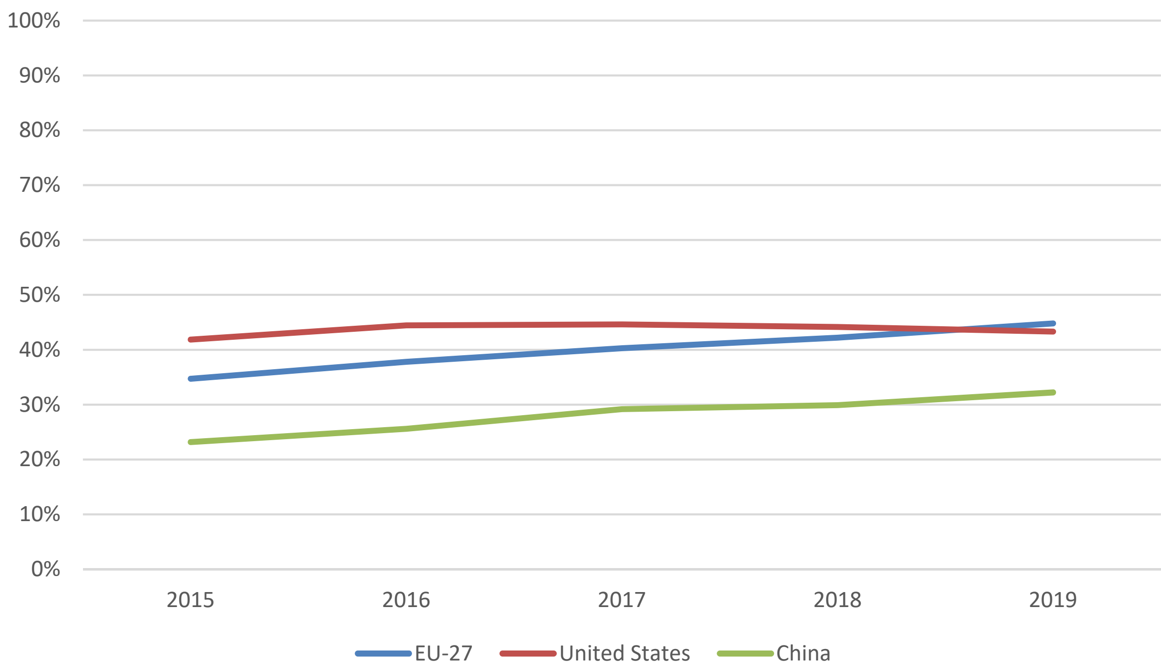
As a building block to the design of future scenarios, we will first review the current drivers and barriers for open science in three different regions. In this report, we differentiate between three aspects of open science: open access, open data and open collaboration. In the following sections, we discuss the drivers and barriers for each aspect in turn, and in the final section we look at the variation across the three regions.

1 Open access

Open access concerns the right to read and reuse scholarly publications at no financial, legal or technical cost to the reader, as long as the author of that article is acknowledged (BOAI, 2002). The development of digital technologies that have made the publishing process both faster and cheaper (Björk, 2004) has enabled the move towards free sharing of scientific publications. The publishing costs ('article processing charges') are covered either by the author or by the publisher or publishing platform that is used. In the latter case, this is often enabled through financial support from deals with governments or research funders or support from the academic community.

In 2018, 36% of publications in the Scopus-database was open access, up from 31% in 2009. When looking at all publications from 2009-2018, several European countries have already passed the 50% mark (EU Open Science Monitor). The Web of Science database presents a similar picture for 2019, including the EU27. Of all 2019 publications, 45% of the EU27 publications and 43% of US publications are available in open access. China lags behind at 32%. Open access in the EU-27 rises steadily, now surpassing the US, where open access shares are stabilising since 2016 (see figure below).

Figure 1. Share of publications available in open access, 2015-2019.



Source: Web of Science, data retrieved February 2021; analysis: Rathenau Institute

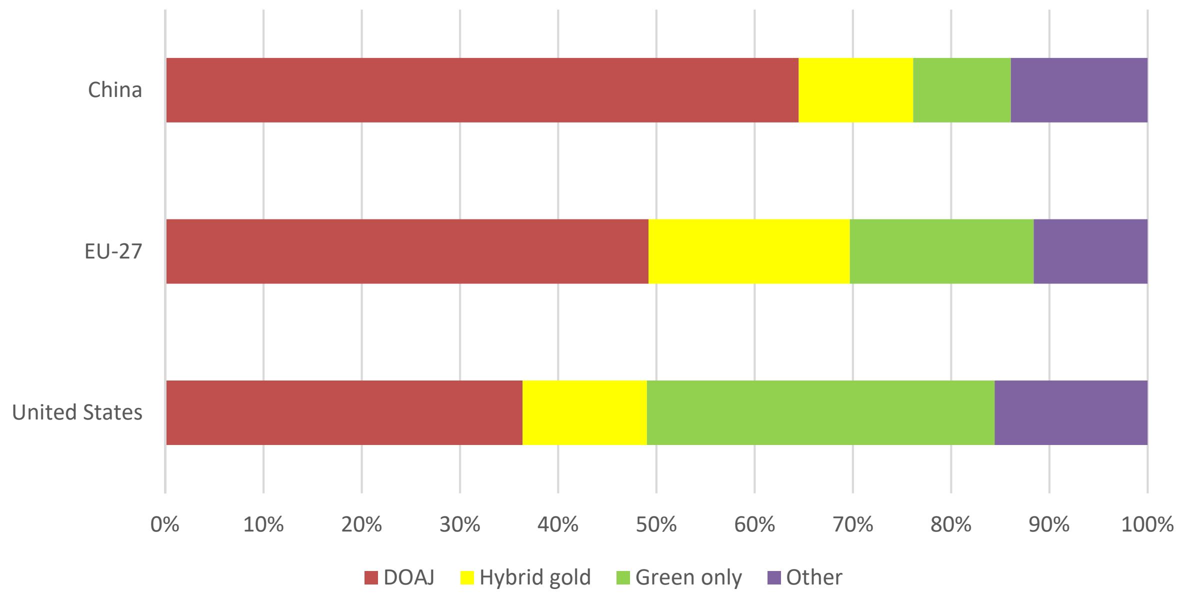
There are several 'routes' by which scholarly research outputs can be published open access (Harnad et al., 2008; Piwowar et al., 2018: Bosman et al., 2021). Most routes are modelled on the conventional journal model.

- The Gold route: a publication is published open access in a scientific journal or publishing platform. There are several varieties:
  - The traditional Gold route: a publication is published in a fully open access journal or platform. The author or his/her institution must pay article processing charges for publication of the article.
  - The Hybrid route: a publication is published in a journal or on a publishing platform that is not normally open access. The author or his/her institution must pay article processing charges for publication of the article.
  - The Diamond route: a publication is published in an open access journal or on an alternative publication platform where no financial contribution from the author or organisation is required. These are often owned and funded by the academic community. Examples of alternative publication platforms are Open Research Europe and the Free Journal Network (Bosman et al., 2021; Van der Graaf, 2021).
- The Green route: an author publishes a version of the publication in a repository.

The prevalence of the different routes varies across the regions under analysis here. The Gold route (including Diamond) plays a large role in China (65% of all 2019 open access publications use this route). In the US, the green route is more important (35% of all open access publications) (Web of science, analysis Rathenau Instituut). This pattern for China and the US is also visible in the analysis of Zhang et al. (2021). The hybrid route plays a relatively large role in the European Union (21%).

The uptake of open access publishing varies strongly across scientific disciplines. The uptake is highest among medical and health-related fields, followed by other disciplines from natural and technical sciences, and the social sciences. Law, arts and humanities show the lowest open access uptake (Severin et al., 2018).

Figure 2. Share of various open access routes in total open access publications in 2019.



DOAJ: Directory of Open Access Journals. Source: Web of Science, data retrieved February 2021, Analysis: Rathenau Instituut.

1.1 Awareness, information and knowledge

Concerning awareness, the most important thing is that funders and institutions aid researchers in finding their way to open access publishing venues and creating appropriate workflows. But awareness should not only be fostered of the technical aspects of how to publish open access, but also of the benefits of open access publishing (D4/D2). It is expected that open access will not just make scholarly publications freely available; it will also make the research process more efficient by making scholarly communication much more interactive and by sharing insights faster (Pinfield et al., 2021). There are at least three ways in which open access changes how research is conducted (Pinfield et al., 2021):

- As open access requires changes in the publishing process, it gives researchers more control over their output and pushes publishers and libraries into new functions as providers of publishing services rather than custodians of content.
- Open access may facilitate open peer review, in which names and comments of peer reviewers are published. Often, multiple article versions, from preprint to final version, become available. Open peer review is not considered appropriate for all disciplines and research communities, though. Where it might create a bias against for instance women or minority groups, this may be offset by blind reviews.
- Open access may encourage sharing of not only research papers, but also other kinds of research outputs that occur earlier in the research process, such as grant proposals or presentations.

Besides awareness of the benefits, there must be awareness regarding the costs and time involved in open access publishing (B4). The sheer diversity of available publication routes and of funders' and publishers' open access policies creates ample legal and practical uncertainties (B3). Publication may happen through a full gold journal, an alternative publication platform such as F1000 or Open Research Europe, in a hybrid journal or in a traditional journal that offers opportunities for green open access.

Currently, more and more research funders require open access publication of results (European Commission, 2019a). These often come with specific requirements, such as a maximum embargo period or a requirement to publish via a specific route to open access (D7). Plan S, for example, requires researchers or their institutions to retain copyright of an article, allows no embargo periods and only allows open access publication in a traditional journal when that journal is on a path to becoming open access (Coalition S, 2018). Publishers, on the other hand, often have conditions that are incompatible with these requirements. For example, they demand a period of exclusivity, during which the article cannot be shared, or they require the copyright of the article to be transferred to them. Alternatively, they may demand high article processing charges to make up for the loss of exclusivity. While the requirements of funders can force researchers to publish open access (D7), they also create a web of rules and regulations in which the individual researcher or project team must find a way.

1.2 Incentives and disincentives for researchers

Researchers generally regard open access as a positive phenomenon, both from a practical and a moral point of view. Practically, open access increases and speeds up their access to other researchers' work. Morally, many researchers support the idea that results from publicly funded research should be publicly available (Greussing et al., 2020; Pinfield et al., 2021). However, some studies have found that this support does not always lead to large changes in publication practices, because researchers experience several barriers on their way to open access publishing (ibid.).

Next to the legal uncertainties and complex regulations mentioned, another barrier towards open access publishing may be concern over the quality of open access journals. While there is evidence that open access publishing creates a citation advantage (SPARC, 2015), many open access journals and platforms do not yet have the reputation of the traditional journals. One study found that researchers' attitudes towards open access journals are ambivalent (Tenopir et al., 2017). An extra source of concern is the rise of predatory journals, which do not perform adequate quality control (Beall, 2013: Greussing et al., 2020). One literature review showed how predatory journals and open access publishing are often connected in academic discussions (Krawczyk and Kulczycki, 2021). These concerns over quality could be a barrier to open access publishing, especially because, as for example a study by Hessels et al. (2019) show, publications are still an important source of recognition for researchers (D1/B1).

Another important obstacle identified by some studies are article processing charges that often need to be paid to get an article published (Weckowska et al., 2017; Greussing et al., 2020: Tenopir et al., 2017). Many research councils now remove financial disincentives by providing coverage of article processing charges (D6). Furthermore, to increase the confidence of researchers, some research councils have engaged in rights retention strategies to create a legal basis for open access publishing (Coalition S, 2021).

1.3 Framework conditions, system adaptations and investments in skills

The different routes to open access publishing all require infrastructures to make articles findable and accessible and to inform researchers about and guide them in the publication process. Several kinds of infrastructures have been developed to this end, both by incumbent organisations and new actors:

- First of all, there are open access journals and publishers (typically charging high author fees) that have their own online platforms.
- Second, there are large institutional and subject repositories, such as PubMedCentral of the National Institutes of Health.
- Third, platforms are being developed that support publication and provide peer review processes – often open peer review processes. These platforms are often funded by the academic community, by learned societies, or by governments or research institutes (Bosman et al., 2021).

A relatively new phenomenon are 'overlay journals' that have their own editorial boards. In addition, they utilise existing platforms or repositories for an open peer review process and publishing (Van der Graaf, 2021).

As a consequence of open access, these publication infrastructures face new technical requirements, as multiple resources pertaining to the same publication must now be linked. A diversity of outputs related to one scientific publication may now be found online, such as a pre-print, different versions of the articles, related data files or presentation slides or open source code. Publishers need to adapt to these changing requirements of the publishing process (European Commission, 2019a). The same applies to academic libraries, whose functions change to a service provider in a digital environment (Pinfield, Cox and Rutter, 2017).

As noted in paragraph 1.1, the increasing variety of infrastructures and publication venues can be daunting. Therefore, tools and services are being developed to aid researchers in tracking open access articles scattered around numerous repositories or in finding their way in an open access publication process and its legal requirements. The Unpaywall database, for example, provides a tested overview of the open access status of articles. The SHERPA/ROMEO databases provide an overview of funder requirements and journal policies regarding open access. PubMedCentral has a service, PubMed International, aiding research funders who wish to develop a similar database for their own home market (NIH/NLM, 2018).

2 Open data

Open data is about sharing research data. It is often defined in terms of the FAIR principles: data should be Findable, Accessible, Interoperable, Reusable. In principle, open data should be discoverable through catalogues and search engines. According to the European Commission, research data should be as open as possible, and as closed as necessary. This implies that research data should be accessible, unless there is a good argument to protect them. Moreover, they should be made available with a minimum time delay. Open data should be documented in a way that allows researchers to use them, including those outside the discipline of origin. And open data should be protected from loss for future use in sustainable, trustworthy repositories.

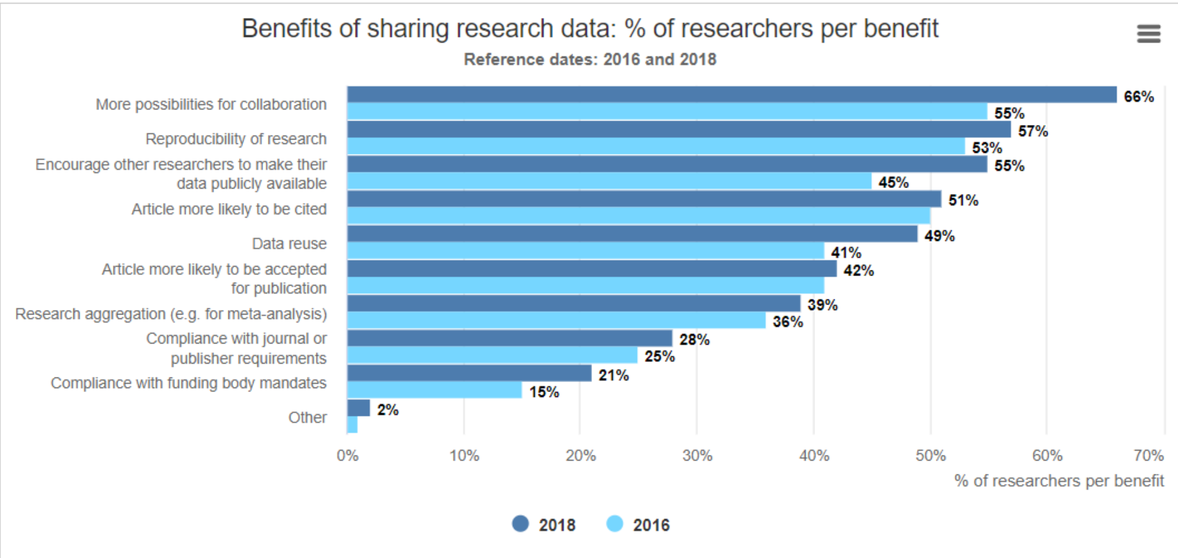
Open data is advocated because it is generally believed to contribute to the efficiency, replicability, and transparency of science. In some fields open data can also enable novel discoveries that would have been impossible without sharing research data.

2.1 Awareness, information, knowledge

Since there is still a lack of awareness among many researchers on the possibilities and benefits of open data, increasing awareness will be a strong driver (D4). Without doubt, many of the initiatives and requirements by funders and journals discussed above will contribute to this awareness. Efforts of academic organisations will also increase awareness. An example is the Open Data Policy and Principles of the Belmont Forum. The Belmont Forum adopted Open Data Policy and Principles at their 2015 annual meeting of principals in Oslo, Norway. 'The policy signals a commitment by funders of global environmental change research to increase access to scientific data, a step widely recognised as essential to making informed decisions in the face of rapid changes affecting the Earth's environment.'

There is an increasing amount of evidence that sharing research data is not only beneficial for society and the economy, but for researchers themselves as well. This evidence (D2) may further stimulate researchers to make the effort of making their data openly available.

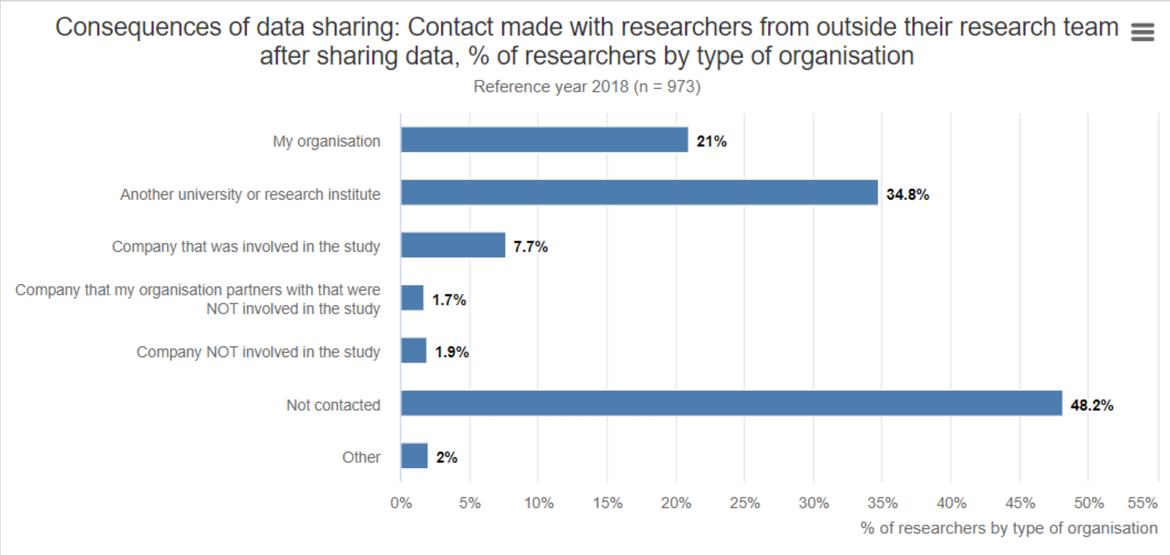
Figure 3. Benefits of sharing research data, according to researchers.



Source: Open Science Monitor (https://ec.europa.eu/info/research-and-innovation/strategy/goals-research-and-innovation-policy/open-science/open-science-monitor/facts-and-figures-open-research-data_en#researchers-attitude-towards-data-sharing

Researchers perceive collaboration possibilities even as the most important benefit of open data (see figure 3). Many researchers report indeed that they were contacted by other universities or research institutes after sharing their data (see Figure 4).

Figure 4. Consequences of data sharing according to researchers.



Source: Open Science Monitor (https://ec.europa.eu/info/research-and-innovation/strategy/goals-research-and-innovation-policy/open-science/open-science-monitor/facts-and-figures-open-research-data_en#researchers-attitude-towards-data-sharing)

There are indications that sharing data can result in greater visibility for researchers and thus lead to a greater citation rate (Piwowar et al., 2007). Moreover, many researchers simply want their research to be transparent and verifiable (Enke et al., 2012).

In some research areas, such as genomics, open data saves researchers time and effort, or can accelerate their overall research progress (Haeusermann et al., 2017). This characteristic also motivates researchers in other research areas. In an interview study, one respondent argued that sharing research materials contributes to the goal of making science a commons (Kaja and Sascha, 2014).

2.2 Incentives and disincentives for researchers

Journals and research funders play an ambivalent role in the promotion of open data. At the one hand, they are the main actors providing incentives for open data (D1, D6). At the other hand, they are key building blocks of the current reward system of science that discourages researchers to openly share research data (see below).

A study shows that 74% of researchers would accept leading journals' data sharing policies (Huang et al., 2013). According to experts, many journals and funders in Europe promote two new practices to allow researchers to get credit for their open data practices: citing data sets in reference lists and linking the data to the articles published by researchers. Over time, we can observe an increase of data sharing practices. A study found that (in the social sciences) this trend is especially visible in journals with higher impact factors (Zenk-Möltgen et al., 2018). In 2017, about 38% of journals treated open data as a condition for publication, while another 29% required open data without an explicit statement regarding the effect on publication decisions.

Thousands of scientific journals nowadays have policies for depositing the data on which their published papers are based. PLOS has promoted this since 2014 with a mandatory data availability policy for all our articles. Since 2016 most larger publishers (Springer Nature, Elsevier, Wiley, Taylor & Francis) have introduced tiered data policy initiatives. In addition there are also discipline-specific policy initiatives, such as in earth sciences. In 2017 a study found that open data is a requirement for 21% of the journals investigated (Vasilevsky et al., 2017).

Scientific publishers under the collective of the STM Association are encouraging authors to cite datasets along the FORCE 11 data citation guidelines. A survey study indicated that the vast majority of geophysical researchers 'would allow other researchers to use their data provided they receive an acknowledgement (90.4%) and/or citations (87.5%)' (Tenopir et al., 2018). A scientometric analysis found that scientific publications that contain a link to data in a repository receive on average approximately 25% more citations (Colavizza et al., 2020).

According to the Sherpa Juliet database, at the moment, many research funders encourage (14.5%) or require (27.6%) open data, but the majority of research funders worldwide (56.6%) still has no policy regarding open data (D6). The European Commission has made Data Management Plans mandatory in Horizon Europe (Burgelman et al., 2019).

Incentives for reuse of research data vary strongly across academic disciplines. Some disciplines have a longer tradition of sharing data such as astronomy and environmental sciences. In other disciplines there is a more competitive research culture that makes researchers hesitant to share and re-use data.

One barrier for open data is that it simply takes time for authors, editors, peer reviewers and editorial support staff to share their data. Most researchers experience it as 'some effort' (57%), while 27% experience 'a lot of effort' to make their research data available for re-use by others (B4). Another significant barrier is the uncertainty about receiving credit for their work (B1). While further distribution of papers with open access typically attracts more recognition, sharing research data openly can weaken a researcher's position in competitive fields by enabling rival research groups to use the data. A literature review indicates that the current academic reward system still does not sufficiently encourage individual researchers to share data and reuse data (Zuiderwijk et al., 2020).

Concerns about being outcompeted (B2) are probably only significant in highly competitive fields. In most research areas researchers will feel little threat because they publish their data together with an article with their own analysis of the data. In this sense, they keep the privilege of being the first to publish about the data set. This was confirmed by a qualitative study in ecology in which only one author expressed concerns about giving up the exclusive access to their data set (Sholler et al., 2019). However, in more competitive fields researchers hesitate to share large data sets. After investing a lot of resources in the generation of data, they may want to publish more than one publication before openly sharing the data (Levin et al., 2016).

Concerns about misuse of data are another significant barrier to open data (B5). A survey among geophysicist indicates that these concerns inhibit both the sharing and reuse of data (Tenopir et al., 2018). Many respondents feel that 'data may be misinterpreted due to complexity of the data' (79%), 'data may be misinterpreted due to poor quality of the data' (78%) and 'data may be used in other ways than intended' (77%). Concerns about data quality and possible misinterpretation also inhibit the reuse of data that have been made open by others (Zuiderwijk et al., 2020).

Privacy issues (B7) can also form a barrier to open data, in particular when working with human subjects. A study among sociologists and political scientists suggests that this issue is particularly relevant for qualitative research data. 'Standardized quantitative surveys conducted at a large scale national level (for instance like national election studies) can much easier be anonymized than surveys of smaller, more special populations. Qualitative studies also often do not have computer code for the analysis, but conduct non-automatic procedures that need to be documented in a different way.' (Zenk-Möltgen et al., 2018).

2.3 Framework conditions, system adaptations and investments in skills

The integration of open science in infrastructures and assistance with tools and services (D3) can strongly drive the development of open data. A wide range of tools such as protocols.io, Code Ocean and Figshare enable researchers to share products of their research, with unique DOIs. In particular, the connection between data depositories and journal publications is potentially powerful. Many journals nowadays assist researchers with recommendations. Many scientific publishers promote the Scholix framework for building linkages between scientific journals and data repositories. This campaign received a boost during the STM 2020 Research Data Year.

A related movement, that seems rather marginal still, is policies for peer reviewed datasets. Journals with such policies tend to be specialised instantiations of a larger journal. This means that these journals often specialise in data publications and therefore may not have the visibility or readership of traditional journals (Sholler et al., 2019).

The further development of open data could probably benefit from adaptation of university curricula (D9), since this would increase the awareness of this and skills to deploy it. Zenk-Möltgen et al. (2018) claim: 'This should be part of the toolkit that young scientists acquire with their overall data skills education. In the same way how universities established courses on quantitative and qualitative methods to train students in data analysis they should also teach data management and data sharing practices.' (Zenk-Möltgen et al., 2018). In the literature we found one best practice of teaching MSc and MA students how to store research data according to the FAIR principles (Wiljes and Cimiano, 2019). However, we have no indication that this is happening at a large scale.

One can also imagine a relationship between citizen science and open data (D10), because in most cases the participation of citizens will stimulate researchers to make the research data openly available. Having said this, we did not come across evidence on citizen science projects working according to FAIR principles.

Lack of skills seems to be a significant barrier for open data (B6). European Commission data visualisations show that in 2018 (merely) 28% of researchers state they have received sufficient training in research data sharing. A study in sociology and political science confirmed that the lack of knowledge about existing infrastructures and insufficient know-how of data sharing are the most important obstacles for realising open data (Zenk-Möltgen et al., 2018).

In order to overcome the lack of skills, education and training can drive the further development of open data (D5). Not only researchers need training to become acquainted with the possibilities and limitations of sharing research data. Other actors, such as journal editors, are also in need of practical guidance. One study of ecology journals found that journals have different mechanisms for ensuring compliance with their data policy. 'In some cases, editorial staff indicated to authors that they would withhold publication until they received a link to the data; in other cases, staff requested data submission in the acceptance letter but did not follow up on compliance prior to publishing the paper. Perceptions of whose responsibility it might be to take appropriate action garnered no concrete answers.' (Sholler et al., 2019).

3 Open collaboration

We define open collaboration as the collaboration between academic researchers and non-academic actors, including industry, governments, NGOs and individual citizens. There is a large literature about open collaboration, covering different areas:

- Transdisciplinary research: collaboration between academic and non-academic partners, often oriented at sustainability challenges, with a focus on participation of not-for-profit actors (OECD, 2020);
- University-industry interactions (and geography of innovation): collaboration between academic and commercial partners, often directed and stimulating industrial innovation (d'Este and Perkmann, 2011), including triple helix literature about interactions between universities, industry and government (Etzkowitz and Leydesdorff, 2000);
- Citizen science: where individual citizens participate as an active partner in the research process (Irwin, 2002).

In the open science discourse, collaboration with public actors and with individual citizens is most prominent. In the academic literature, however, most attention has been paid to collaboration with industry, and for most disciplines this is currently the most common form of open collaboration. In this section we will address collaboration with citizens, public and private actors, while trying to acknowledge the differences between these types of collaboration in terms of drivers and barriers. It should be noted that there is a potential tension between collaboration with industry and open data and open access to research outcomes, because sharing data and outcomes at an early stage can compromise the competitive advantage of industrial partners. In this sense, not all collaborations with industry qualify as open science.

3.1 Awareness, information, knowledge

Although there is evidence that open collaboration generates career benefits for academic researchers (for instance in many fields co-publications with industry receive more citations), many researchers hesitate to engage in this. Their worries seem to concern the amount of credit such open collaborations yield. This perception has been enhanced by the emphasis on scientific publications in the academic reward system related to quantitative evaluation systems based on bibliometric indicators (Gläser and Laudel, 2007) that tends to undervalue societal impact. A second catalyst for this potential barrier is the rise of excellence policies (OECD, 2014), funding and evaluation instruments that stimulate a rather narrow concept of academic achievement. They typically do not include open collaboration (Rathenau Instituut, 2019a). The perception of researchers that open collaboration yields less credit implies that more evidence of the benefits of open collaboration for researchers (D2) could make a big difference.

Uncertainty about socio-economic benefits of open science (B8) will probably not directly influence the choices of researchers to engage in open collaboration, but it may hamper the commitment of policy-makers and research funders to open collaboration. Also, public trust in science is lower when it involves research funded by industry (Rathenau Instituut, 2018). This may curtail the further development of policies and funding for university-industry collaborations (B8).

Conversely, an increasing awareness of open collaboration and its benefits will stimulate policy-makers and research funders to stimulate and reward open collaboration (D4). Contrary to the other dimensions of open science, open collaboration is not a new phenomenon. Hence, one may assume that there is sufficient awareness among researchers of the possibility to collaborate with non-academic partners.

Many qualitative studies have shown how various types of open collaboration generate benefits for society and the economy (D'Este et al., 2018). There is also quantitative evidence that collaboration with industrial partners creates economic benefits (Mascarenhas et al., 2018; Sjöö and Hellström, 2019). Open collaboration also fits in the trend of open innovation, in which industrial innovation strategies rely more on collaboration with external partners, including academia (Chesbrough, 2003). The industrial interest to collaborate with universities is partly due to the shift in their own R&D capacity from (fundamental) research to (product) development.

In Europe there is political consensus about the benefits of open collaboration, as the European strategies for artificial intelligence and the European Green Deal demonstrate. Both strategies include public-private partnerships and other forms of open collaboration as elements to realise societal change and/or economic competitiveness.

3.2 Incentives and disincentives for researchers

The perceptions and experiences with open collaboration vary strongly across disciplines. 'Social scientists and clinical researchers may be used to co-designing and co-producing their research with citizens and patients, chemists may be used to sharing their knowledge in close partnerships with industry, but many fields of science remain wary of any distortion of the academic scientific process by outside interests. The notion that only scientific peers are qualified to judge what areas of research merit funding and what the priorities in these areas should be is indeed still alive.' (Dai et al., 2018).

There is a particularly strong barrier for collaborating with industry, because industry often poses restrictions on the way researchers can communicate and share research results. A recent survey confirms that most researchers, if given the choice, prefer to work with other partners (van Rijnsoever and Hessels, 2020). This means that they will need special incentives to engage in these collaborations. Apart from funding, clear agreements about the possibilities to share research data and results are required to make sure that these collaborations comply with open science.

The hesitation of researchers to collaborate is weaker with public partners, possibly because academic researchers align more easily with public values than with industrial goals (competitiveness). Still, researchers need to see more clearly what the benefits are of collaborating with citizens or public organisations. Otherwise, the current competitive science system will make them avoid these types of collaboration due to concerns of being outcompeted (B2).

Nowadays, there is wide consensus about the limitations of quantitative indicators in research evaluation (Hicks et al., 2015). Many scientific organisations around the world have signed the San Francisco Declaration on Research Assessment (DORA) to commit themselves to a broader approach to research evaluation. Although the current reward system seems rather inert, this should help to broaden the academic reward system and give credit to other types of achievements than merely publications in peer-reviewed journals. A front-runner in this respect is the 'Recognition and rewards' programme of the Dutch universities (https://vsnu.nl/recognitionandrewards/recognition-and-rewards/index.html) that also pays attention to collaborative skills and to open science (D1).

Researchers tend to be most comfortable in collaboration with similar actors (van Rijnsoever and Hessels, 2020). Due to different institutional conditions, it is more difficult to collaborate with non-academic partners (Boschma, 2005). This implies that there are additional costs in terms of energy and time to overcome organisational distance, in particular with organisations that differ most from academic organisations, such as local governments or SMEs (B4).

Very few researchers are sensitive to direct financial rewards, in the form of personal bonuses (Lam, 2011). However, they depend strongly on external funding to carry out their work. Therefore, conditions and criteria formulated by research councils and other funding organisations can strongly influence research practices, including open collaboration. The influence of these incentives will vary across regions, depending on the relative financial autonomy of researchers. In the US, many researchers (especially at more prestigious universities) receive a larger share of institutional funding. This allows them more autonomy to choose their own collaboration partners.

The available funding from industry, either in cash or in kind, can also form an incentive for open collaboration (although this will not necessarily entail open access and open data). In the EU, the contribution of the business sector to academic research (HERD) is around 7.0%, against 5.4% for USA, 7.9% for Canada and 3.3% for Japan. There is large variation within the EU, from 2% for Portugal to 13% for Germany (OECD, MSTI 2018).

Over the years, EU Framework Programmes (FP) have created strong incentives for open collaboration. In an increasing number of the instruments within FPs, collaboration with non-academic partners is a requirement in order to qualify for funding or it will give a higher score in the selection process. In the water sector, for example, this has helped to strengthen the networks between universities and non-academic partners (Heringa et al., 2016). The new FP, Horizon Europe, only includes one pillar dedicated to academic research without open collaboration (Excellent Science, 26% of total funding). Pillar 2 (Global Challenges and European Industrial Competitiveness, 56%) and Pillar 3 (Innovate Europe, 14%) will mostly support projects that include active participation and/or funding from non-academic partners. Encouraged by the Lamy report (Lamy Committee, 2017), Horizon Europe will also support different forms of citizen engagement and citizen science.

Many national research funders also stimulate collaboration, in particular between universities and industry. There is a range of instruments for this, such as the collaborative research centres program of the NSF in the USA (https://iucrc.nsf.gov/), or Topconsortia for Knowledge and Innovation in the Netherlands (https://www.topsectoren.nl/innovatie) (OECD, 2016). These collaborations do not necessarily include open access and open data, however.

3.3 Framework conditions, system adaptations, skills

Due to the complications of working with non-academic partners discussed above, a lack of skills can be a barrier to open collaboration, in particular when working with public actors or citizens that are unfamiliar with scientific routines (B6). Studies on transdisciplinary research have shown that individual skills are a key to open collaboration (Hoffmann et al., 2017; Wiek et al., 2011). In this literature, scholars argue both for education and training in communication and collaboration skills to academic researchers (D5), and for adaptation of university curricula (D9) to educate future researchers with more transdisciplinary competences (OECD, 2020). So far there is no evidence that these changes are realised on a substantial scale.

Citizen science also takes a lot of time. However, this can be worth it in some disciplines, thanks to the additional capacity that citizen scientists contribute, in particular when they help in collecting data (Bonney et al., 2016) (D10). In the case of citizen science it is easier to involve highly-educated volunteers than to work with people that have a low affinity with academic research (Brouwer and Hessels, 2019) (D10).

Studies on university-industry interactions pay less attention to the importance of skills, possibly because the cognitive distance with industrial partners is often smaller. There is a steady growth of education and training in academic entrepreneurship (e.g. the KICs within the European Institute of Technology), but this is oriented more at developing new businesses than on increasing open collaboration.

4 Open science: a geographical comparison

In this section we compare the open science policies of the United States, China and the European Union.

4.1 China

In order to improve national innovative capacity and industrial competitiveness, China has been investing heavily in R&D. R&D-expenditure has risen from 0.56% of GDP in 1996 to 2,23% of GDP in 2019 (OECD, MSTI 2020-2). It is now spending a larger share of its GDP on R&D than the European Union (2.10% of GDP) and is closing the gap with the United States (3.07% of GDP in 2019). In absolute figures, China is now spending almost the same amount on R&D as the US (Eurostat). In 2019, China surpassed the US as the country with the highest number of scientific publications (Rathenau Instituut, 2020, based on CWTS/Web of Science analysis).

This growth has come with public policies that stimulate university-industry collaboration over the past decades (Su, Zhou et al., 2015). The business sector in China is both a large R&D funder (77%, against 59% in the EU-27) and R&D performer (76%, against 66% in the EU-27) (OECD, MSTI 2020-2). The drive for business collaboration with academia has primarily resulted in private funding for R&D. 29% of research at universities is funded by the business sector, against 7% in the EU-27 and 5% in the US. However, scientometric analysis of co-authored publications suggests that "Chinese universities are much less active in collaborations with industry in terms of either publication productivity or collaboration intensity" (Zhou, Tijssen et al. 2016). This gives the impression that open collaboration is somewhat limited. However, this is difficult to quantify.

In terms of open access, China is lagging somewhat behind as well, compared to the other countries in the analysis, with 32% of scientific publications available in open access in 2019, against 43% in the US and 45% in the European Union (based on Web of Science). This may be due to the fact that publishing in high-ranking, English journals is considered to be important both for the careers of individual researchers as well as for the international visibility of Chinese research (Zhang and Sivertsen, 2020). Chinese researchers often get paid to publish in prestigious journals (Abritis and McCook, 2017). However, there is a growing concern in China that due to these publication practices, research does not sufficiently benefit the development of China itself, because many local universities and science parks do not have access to these international journals (International Science Council, 2019).

Open access offers a way to serve domestic needs while maintaining international visibility. In 2014, the Chinese Academy of Sciences (CAS) and the Natural Science Foundation of China (NSFC) issued open access mandates, requiring green open access of peer reviewed versions of journal articles resulting from publicly funded research (CAS) or research they funded (NSFC) (van Noorden, 2014; Schiermeier, 2018). Both organisations allow a 12 month embargo period. Institutional mandates do not seem to play a significant role in China. Since then, the CAS and NSFC have both developed institutional repositories (International Science Council, 2019). The NSFC has a Basic Research Repository. The CAS has a network of 114 institutional repositories (in 2019) and plays a large role in the institutional repository system in China. The OpenDOAR database now lists 60 Chinese repositories (including Hong Kong), of which 38 are from CAS institutes. Zhong and Jiang (2016) find that not all repositories offer full open access, including both the right to read, reuse and spread an article. They conclude that the CAS repositories offer full open access, whereas most university repositories do not have a copyright policy, or only very implicitly.

Despite this focus on repositories, the gold route to open access (publication in journals in the Directory of Open Access Journals) seems to be favoured by Chinese researchers (Zhang et al., 2021). A 2018 survey showed that most Chinese researchers are familiar with open access journals and have a positive attitude towards them (Xu et al., 2020). When making decisions with regard to publishing, they do sometimes choose open access. However, they prefer the journals indexed in reputable databases. This could be due to the importance of traditional quality indicators in research evaluation and concern for predatory journals, which is high in China (Van Noorden, 2014). It is therefore important to note that the need to balance internationalisation with domestic needs is causing a few first steps towards changing the research evaluation system. At the beginning of 2020 the Ministry of Education and the Ministry of Science and Technology published policies to give more attention to qualitative, peer review indicators (Zhang and Sivertsen, 2020).

Regarding open data, the Chinese government has recently implemented a strongly centralised policy. In 2018, the State Council has decreed that all scientific data generated in China must be submitted to government-sanctioned data centres before appearing in publications. The science ministry is responsible for creating a national data centre, but other ministries and local governments are expected to create their own centres as well. Exempted from the call are data involving state and business secrets, national security, "public interest," and individual privacy (Normile, 2018).

4.2 United States

Many initiatives to promote open access and open data have originated in the United States. For example, the Open Science Data Cloud was launched in 2010 by a consortium of American partner organisations (Grossman, 2010). And arXiv.org, one of the first and best known preprint servers, was developed in the US and has been maintained by Cornell University. The National Institutes of Health have made open access publishing in their PubMedCentral repository mandatory since 2008 (with a 12 month embargo). Currently, several US government funders, amongst which NASA, EPA and the CDC, use the PMC database. A European branch has been created and PMC International helps funding organisations in other parts of the world to build national or regional repositories. Today, the US has a relatively high percentage of 'green route' open access. 35% of open access scientific publications from 2019 is available only via the green route, versus 19% in the EU and 10% in China (Web of Science, analysis Rathenau Institute).

Since 2013, the US federal government requires public online availability of results of publicly funded research within 12 months of publication in a journal (Subbaraman, 2019 in Zhang et al., 2021). In the same year, the Office of Science and Technology Policy (OSTP) ordered all federal agencies with more than 100 million dollars annual R&D expenditure to develop plans to increase public access to the scholarly publications and digital data resulting from the research they support (Obamawhitehouse archives). Open data is required when compatible with confidentiality and privacy concerns and does not contradict proprietary interests (Heather, 2016). As of January 2017, all agencies have such plans. Amongst other things, all agencies have designated repositories to realise access to publications. The National Institutes of Health, one of the largest research funders in the US, has implemented new data sharing policies in 2020 requiring all recipients of major funds to create and submit to the NIH a Data Management and Sharing Plan (a "Plan") outlining how scientific data and any accompanying metadata used in research will be managed and shared (National Law Review, 2020).

At the end of 2019 there were some signals that the US government was considering to demand immediate open access for results of federally funded research (Subarraman, 2019, SPARC, 2019). In February 2020 the OSTP set out a Request for Information on "approaches for ensuring broad public access to the peer-reviewed scholarly publications, data and code that result from federally funded scientific research." (Federal register, 2020). The results are as of yet unclear.

Institutional mandates play a much larger role in the US than in China, where there are 167 open access mandates, of which 154 are issued by research organisations (ROARmap, data April 2021). Of the 16 funder mandates in the Sherpa-Juliet database, 10 require open data archiving. The US also has by far the largest number of data repositories: 1.048 (European Commission, Open Science monitor, 2019).

Read & publish deals, where institutions cover both subscription fees and article processing charges (APCs) so that authors can publish gold Open Access, seem to play a smaller role in the US, with only 13% of 2019 open access publications being published in hybrid journals, against 21% of EU-27 open access publications. Zhang et al. (2021) show that hybrid publications play a significantly larger role when the publications are the result of international cooperation. Nevertheless, there are some movements towards read & publish deals in the US. In 2020, the University of California – responsible for nearly 10% of all US publishing output – has cut its ties with Elsevier (UC office of the president, 2019) and entered into a transformative open access agreement with Springer (UC Office of Scholarly Communication, 2020).

In the area of open collaboration, there are some initiatives to stimulate collaboration with a variety of stakeholders. For example, one part of the mission of the Centre for Open Science is that all stakeholders must be included and respected in the research life cycle. In January 2018, the Federal Crowdsourcing and Citizen Science Act was signed. A move towards more citizen involvement in science is thus visible, as in Europe. However, this turn is not as radical as in the areas of open access and open data.

The amount of collaboration initiatives between higher education institutes and private parties in the US is comparable to the OECD and EU27 averages, although private non-profits seem to be slightly more important. Both in the EU27 and the US, 16% of R&D at higher education institutes is funded by a third party (Eurostat, adaptation Rathenau Instituut: Rathenau Instituut, 2020a). However, in the US a much larger share is funded by private non-profit. Businesses fund 5% of R&D at higher education institutes, versus an average of 7% in the EU. 7% of university publications is the result of a public-private collaboration, similar to the OECD average (Rathenau Instituut, 2019b).

4.3 European Union

The European Commission's open science policy centres around eight ambitions that include openness of the results of publicly funded research. In addition, they entail the development of both physical and social (evaluation) structures that will enable researchers to comply with open science requirements (European Commission, 2019b). The Framework programmes are an important vehicle to implement open science requirements and stimulate open science practices.

From 2006 onwards, the European Commission has invested in research for and development of the required infrastructures to share research publications and data on a European level. A series of projects known under the name OpenAIRE was launched – and is still running. OpenAIRE has worked on pilots for open access and open data, supporting the implementation of open access in Europe, creating both a human and a technological infrastructure for open access and open data and improving the discoverability and reusability of H2020 research publications and data (OpenAIRE, 2021).

Two central pieces of infrastructure that have been developed are Open Research Europe and the European Open Science Cloud (EOSC). The first is a platform that offers an open peer review process for all H2020 and Horizon Europe research results. After peer review, it includes the article in a renowned index database and a repository. The EOSC, that should be operational for all EU-researchers by 2025, is a federated structure to store, share, process and reuse digital research objects, among which open data (European Commission, 2016). It must enable interoperability between various decentralised databases. Finally, it must become available beyond the research community.

After pilots, open access was made mandatory under H2020 (2014-2020), with a six month embargo period. With 45% of research publications from 2019 free to read, the European Union is on par with the US in the development of open access. The hybrid and gold routes play a more important role in the European Union than they do in the US (data from Web of Science, analysis Rathenau Instituut).

The new Framework Programme, Horizon Europe, demands immediate open access, including both the right to read and to reuse the materials (European Commission, 2021; European Commission, 2018). Information must also be provided about "research output or any other tools and instruments needed to validate the conclusions of the scientific publication" (European Commission, 2021, p.108). Authors must, therefore, retain sufficient intellectual property rights to comply with these open access requirements. Moreover, under Horizon Europe no reimbursement will be available to cover APC charges of hybrid journals. These developments are in line with Plan S, a plan launched in 2018 by several (mainly European) funders – including the European Commission – to demand immediate open access (CoalitionS, 2018).

The same Framework programmes have long fostered collaboration between the research, business and government sectors through making such cooperation a requirement for funding in several parts of FP7 and Horizon 2020. Citizen science and citizen engagement were researched and promoted through the Science with and for Society programs in the last three framework programmes (European Commission, 2020). In Horizon Europe, public engagement and citizen science are promoted as an integral part of the programmes (European Commission, 2021). With this focus on citizen science, as well as the new mission orientation, incentives for open collaboration are likely to increase under the new framework programme. However, there are also concerns that the disappearance of a separate programme for Science with and for Society will lead to a decrease of attention for interactions between science and society (Rathenau Instituut, 2021).

Finally, European Open Science policy priorities focus on new ways to recognise and reward researchers for their open science practices. The focus is not just on rewarding open science practices, but also on investing in the development of new metrics to make open science practices and results more visible. One study (Saenen et al., 2021) found a shared objective at universities to move away from a focus on quantitative metrics. Yet, it is found difficult to create awareness and incentives to realise the change.

These developments demonstrate that, compared to China and the United States, the European Union takes open access and open data policies a bit further. In the areas of open access and open data, the focus seems to lie more on enabling reuse and sharing intermediate research results. In addition, there seems to be more attention for recognising and rewarding open science practices.

OPEN ACCESS, OPEN DATA AND OPEN COLLABORATION IN FOUR SCENARIOS

1 Geopolitical developments and coordination mechanisms

In order to construct plausible future scenarios for open science in China and the USA, we consider two main dimensions. The first concerns geopolitical relationships: are international relations generally cooperative or adversarial? We opted for this dimension, because our main focus in this report is the influence developments in science in the main power blocks of this world exert on the state and quality of European science. We assume that these developments are affected by the mutual relationships between the blocks. The second dimension regards coordination mechanisms in society: is coordination mainly based upon (market) competition, or upon governance through hierarchies and networks? We chose this dimension because we assume that the dominant coordination mechanisms in society are reflected in the way countries organise and govern their public research.

We believe that variation in these two dimensions has major implications for the development of open science. Moreover, developments in both dimensions are fairly uncertain over the coming ten years. This makes them suitable for the construction of plausible scenarios (see e.g. Peter Schwartz, 1991). Before characterising the scenarios, we describe the two dimensions in more detail.

The **horizontal dimension** reflects geopolitical developments, distinguishing between a future with harmonious international relationships and a future with international conflict.

On the **left side**, international tensions and strife mount, conflicts of various natures rise, originating for instance in economic interests, access to resources, or political ambitions. Mutual trust suffers and the willingness to resolve issues and cooperate are severely strained. Such a world moves toward more fragmentation. Economic development is more regional. Global trade suffers, international capital flows decrease, cross-border mobility of people diminishes, calls for more investments in defence and defence-related research increase. As a consequence of rising international tensions, the integration of the Chinese scientific ecosystem in the global, formerly American-European system stalls and partly reverses. The Chinese system gets to be more inward-looking; east-west collaboration decreases; Chinese develops into the lingua franca of Asian science. Given the growth rate and eventual size of the Chinese system, its characteristics are well on their way to become the global standard.

On the **right side**, international tensions can be managed in an *entente cordiale*, conflicts can be mitigated and a necessary degree of harmony can be maintained. The benefits of mutual respect, international trade and collaboration on key global issues are widely recognised. This world remains on the path of global integration. Businesses operate internationally, production chains cross many borders, trade flourishes, flows of foreign direct investment grow, now more so from east to west (amongst others as part of the BRI) than the other way round. The scientific ecosystems integrate into one global system. Collaboration in science grows and is stimulated by governments, researcher mobility remains high, cross-border research funding meets ever fewer obstacles, university relations with business and governments are ever less limited to within-block relations. The structure and governance of this system is based upon the features and traditions of the American-European system, but due to its sheer size, the Chinese component starts to dominate.

The **vertical dimension** displays the dominant interaction and coordination mechanisms in society, distinguishing between the market on the one hand, and a combination of networks and hierarchy on the other hand.

On the **lower side**, competition is the main mechanism of interaction and coordination between autonomous actors. The development of organisations - including universities - is based upon competition, as is the allocation of resources. Economic relationships between actors, both regionally and internationally, are organised through markets. Business interests related to economic growth through innovation are important drivers of research. Universities compete in different ways, for funding, for reputation and for students. Researchers compete for research grants, for publications and citations, and ultimately for tenure. Universities are autonomous in the determination of their research agendas. Nonetheless, they are dependent upon external sources of funds. Within the confines of the science system, businesses play an important enabling role. Scientific publishers retain their role in organising the distribution of scientific output. Furthermore, they organise the system of quality control through peer review. Big tech firms increasingly provide the data platforms to collect, store and exchange scientific data. This enables them to exert an influence on the governance and assessment of science and on its development strategy. With regard to openness in science, a world where competition is the main societal coordination mechanism is not conducive by nature to transparency, sharing and open collaboration.

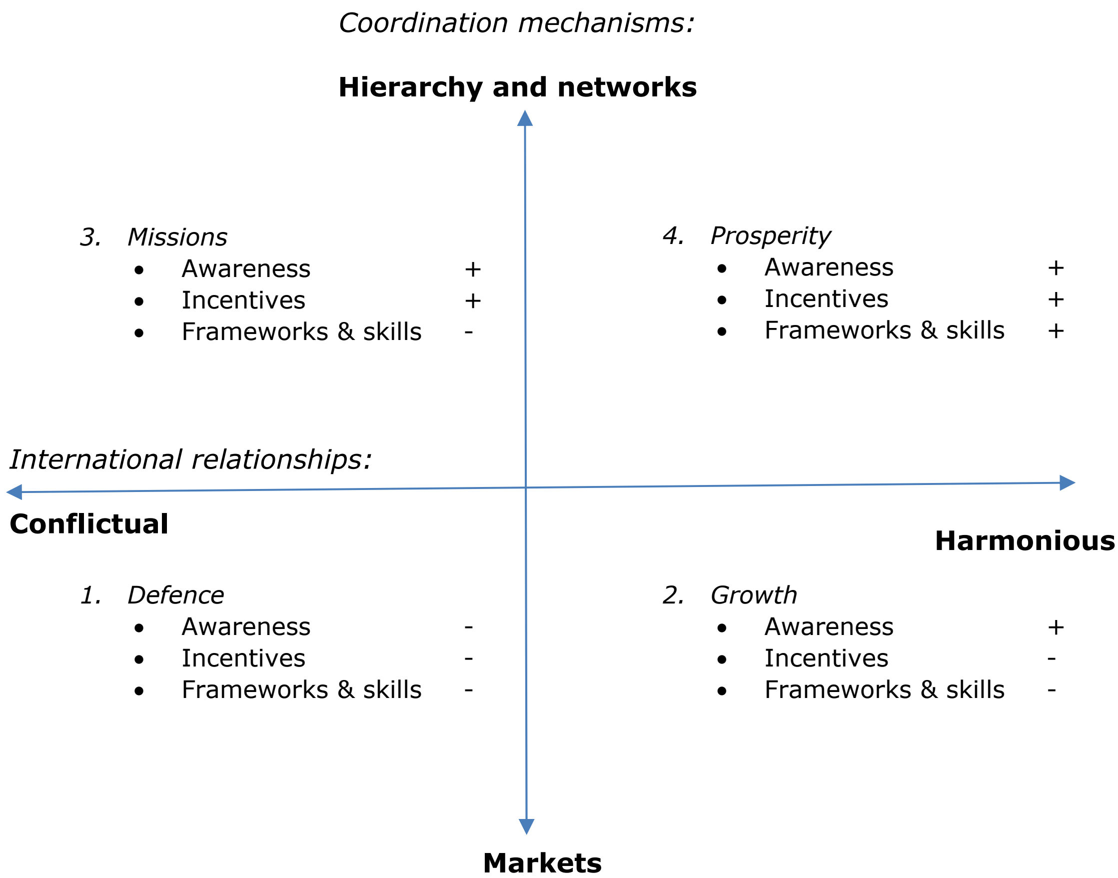
On the **upper side**, interaction and coordination are less mediated by markets and more managed by public policies. These public policies direct scientific efforts by a variety of means, among which agenda setting processes, dedicated research funding programs and network development. Public policies can ensue from more or less democratic procedures and be more or less legitimate. These policies direct scientific efforts to attain collective goals and serve collective interests. They can for instance aim to deal with grand societal challenges, contribute to global public goods, stimulate responsible research and innovation, or attain sustainable development goals. On this side of the spectrum, it is not businesses and business-like universities that are the dominant players in the field, but public organisations and networks of researchers. Universities operate in a coordinated way towards addressing grand societal challenges that are identified by policy-makers. Researchers are not so much rewarded for individual results in the form of publications, as for their contribution to joint efforts. Universities are funded to collaborate nationally and internationally. Concerning openness in science, coordination by aligning science policies and by collaborating in networks match naturally well with openness and sharing as principal elements of the organisation of science.

2 Four scenarios for open science

The figure below (Figure 5) provides an overview of the four scenarios that emerge from these two dimensions. The scenarios focus on the dynamics in China and the US. Sometimes they mention developments in Europe as well, because the regions do not operate in isolation. The names of the scenarios refer to the strategic orientation of science in each scenario, which will be explained in the text below.

In the first chapter, we aggregated the drivers and barriers we were asked to consider into three distinct groups: i) awareness, information and knowledge, ii) incentives and disincentives for researchers, and iii) framework conditions, system adaptations and investments in skills. We use these three groups to characterise each of the scenarios below. In every scenario, each group of drivers and barriers either helps aspects of open science develop further in the US and China (+), or hampers its development (-).

Figure 5. Four scenarios for Open Science



2.1 Defence

Bottom/left: high geopolitical tension – competition as the principal mechanism of coordination.

This is a highly competitive, fragmented, low trust world. Business heavily influences politics and therefore a main *raison d'être* of publicly funded science is to serve business interests. Competition between universities is fierce, barriers between academic ecosystems are increasing. Collaboration is limited and researcher mobility is more homeward than outward bound. Big business firms retain a powerful role in the publication and distribution of research papers and play a big part in research data services. Because security concerns loom high on political agendas and a fair amount of scientific research is therefore oriented to military applications, we call this scenario *Defence*.

Drivers and barriers:

• Awareness, information and knowledge	-
• Incentives and disincentives for researchers	-
• Framework conditions, system adaptations and investments in skills	-

The climate in this world is not conducive to open access, open data and open collaboration. Neither the United States, nor China implement strong policies to stimulate open science. In the United States, open access publication opportunities are limited as publishers maintain barriers to the sharing of articles and require high fees to publish in open access journals. The government and research funders like NSF and NIH support opt-out options to open access policies, to protect national security and business interests. When it comes to building open access infrastructures, traditional publishers and their journals remain important players.

For individual researchers, renowned journals are still the main platform both to publish articles and to access them. Moreover, for universities, a system based upon publishing in open access journals is as expensive as a system based upon subscribing to traditional journals. Journal impact factors continue to be important quality indicators. Although groups of researchers may favour more openness, there is little to no support from governments or research councils. There are numerous small repositories and alternative publication platforms driven by the research community. Due to a lack of coordination, uniform guidelines and legal uncertainties, publishing on these platforms remains time-consuming and findability of papers is problematic. Consequently, where open access is available, green routes are most commonly used, but forced by academic publishers, they require long embargo periods.

Furthermore, in the United States, academic publishers diversify their business into research data services. Linked to their journals, they set up lines of business to store data, to curate and document them and to provide access. All for a fee. They compete in this market with big tech conglomerates like Alphabet (Google) and Amazon, that have developed into leading providers of cloud services and search algorithms, both unique selling points in a market for data services. Therefore, open data in the United States are not all that open: even if the data themselves are for free, the data services are big business.

As competition is paramount for American universities, open collaboration hardly occurs. US universities collaborate very little with non-academic civil society partners. Academic research organisations are largely profit driven, especially concerning applied research. Therefore, they are oriented towards contract research for businesses and governments. Universities cooperate with firms, but only in the form of (exclusive) strategic partnerships, mainly within national borders. Due to the international tensions, universities are barely allowed to collaborate with firms from abroad.

China goes its own way in this scenario, hidden from view behind visa requirements and internet controls. It may or may not invest in developing high-quality Chinese full gold open access journals. This will be to no avail to researchers in the west: access from other regions to the Chinese internet is severely restricted. China will most likely not enter into read-and-publish deals with western publishing firms, because many of its universities hardly benefit from those. By law, Chinese data are to be kept and guarded on server platforms stationed with the Chinese national borders, to which access from outside China, and maybe also from within, is meticulously regulated, checked and controlled. Chinese firms maintain some strategic (exclusive) partnerships with foreign universities, but due to language barriers, Chinese universities hardly collaborate with foreign firms.

2.2 Growth

Bottom/right: geopolitical harmony – competition as the principal mechanism of coordination.

This is a competitive world, though fairly harmonious in a geopolitical sense. As business interests are a dominant force in decision-making on public policy and public spending, public research is predominantly oriented towards contributing to business development and commercial innovation. Hence the name *Growth*. Although competition among businesses and between universities is fierce, there are no barriers preventing cooperation across borders. On the contrary, competition evolves on a global scale. Researcher mobility is an important vehicle for this. As in the *Defence* scenario, big business maintains its grip on the publishing and distribution of research papers and invests massively in the development of data services.

Drivers and barriers:	
• Awareness, information and knowledge	+
• Incentives and disincentives for researchers	-
• Framework conditions, system adaptations and investments in skills	-

Whereas in the former scenario the Chinese scientific ecosystem became more and more isolated from the American and European ecosystem, we here observe a further gradual integration of China into a common global science ecosystem. This system is characterised by common organisational principles and governance arrangements for science, pertaining for instance to human resource management, quality control and research ethics. Within this global system, countries compete to provide an attractive academic climate as an important aspect of the business climate. This competitive nature of the world is reflected in the way science operates and researchers behave. It hinders the free circulation of data and publications.

Both in the United States and in China, open access journals can be mainly found in the medical, technical and natural sciences. The development of other forms of open access, such as open access books, mainly of interest to the humanities and social sciences stagnates. This applies to the development of 'diamond' open access as well, as this is left to publishers and researchers themselves with little financial support from governments and research funders. Because researcher reputation still depends upon publications in high-impact journals and citation impact, the gold and hybrid publication routes are most important. Full gold open access journals and their publishers grow, although libraries, governments and research funders press publishers to decrease their costs and end 'double dipping'. Researchers and libraries join to organise collective pressure on publishers to lower costs of reading and publishing and develop bottom-up open science alternatives to share knowledge, data and papers.

Like in the *Defence* scenario, data services are taken up by business firms. Barriers and security concerns regarding data sharing are far less paralysing, as geopolitical relations are much more relaxed. Steps are taken within research organisations to optimise the use of available research data and thereby reduce the inefficiencies of repeated collecting of similar data, of non-standardized data quality, and the like. To this end, research organisations put an effort into increasing data awareness among their researchers. They resolve issues regarding data ownership, rights to data and privacy. They team up with big tech data service businesses to invest in data curation, in safeguarding data quality and in the exploitation of research data.

In this scenario, academic research is mobilised for economic growth. The strengthening of international markets for research facilitates collaboration between academic and industrial partners, but competitive pressures on research organisations remain an important bottleneck for true open collaboration. Given peaceful international relations, academic collaboration easily crosses international borders, supported by digital technologies, including advanced translation tools. However, the collaboration with non-academic partners remains small. The share of industrial funding for university research, in China traditionally quite substantial, has further increased, and has grown also in the US. Despite this, the traditional role division between industry (knowledge user) and university (knowledge producer) remains. There is also little collaboration between academic and civil society organisations. And citizen science is still a marginal phenomenon: citizens mainly participate in research in an instrumental role, for instance in test panels for innovative products and services.

Along these lines, we observe some progress towards open science in both the United States and China. This is largely driven by business and only continues as long as it remains in accordance with business interests. Both established scientific publishing companies and newcomers from the ranges of big tech firms vie for a lucrative piece of the cake. European open science policies are not well aligned with the general scientific climate in the United States and China. The traditional organisational paradigm of science does not easily tolerate too much openness and sharing. But new digital technologies greatly facilitate exchange of data and papers and online collaboration, and therefore lure companies into exploring new business models for the distribution of scientific information. There is some bottom-up small scale activity to promote open access and open data among researchers and research organisations at the grass roots level. However, there is not enough support from institutions and government for it to grow into a real alternative to the services offered by academic publishers.

2.3 Missions

Top/left: high geopolitical tension – more cooperation and mission orientation.

This is a world where governments increasingly seize the initiative to address a number of pressing issues and grand societal challenges, at least in the west. Public goals, health and security concerns and urgent global threats have superseded economic competitiveness as the main drivers of economic, industrial, research and science policies. Public authorities rally research and innovation capacities behind a shared agenda of societal missions by directing public spending, by changing tax policies to reward sustainability and by regulating industries.

Part and parcel of this policy package is an intensification of science policies stimulating openness, sharing and collaboration. Geopolitical tensions and conflicts help to solidify transatlantic cooperation and stimulate the United States and Europe to move together on numerous policy issues. On both sides of the Atlantic, governments take the lead in reinforcing, restructuring and redirecting research towards achieving societal goals, in an attempt to confront the rapid growth in research spending in China. A transition to open science is pursued to speed up research and increase the efficiency and effectiveness of public research spending. This pursuit is obstructed, though, by a lack of internationally shared standards and frameworks, security concerns, threats of espionage and theft, and a general fear of being outcompeted.

Drivers and barriers:

- Awareness, information and knowledge +
- Incentives and disincentives for researchers +
- Framework conditions, system adaptations and investments in skills -

In the United States public investment in science is more coordinated, more mission oriented and more aimed at tackling grand societal challenges than it has been during the first two decades after 2000. Strides towards open access are made, also because research communities continue to push bottom-up for more open access and supporting infrastructures. However, as both the United States and China guard against the spilling over of sensitive knowledge and technologies, embargo periods may be geographically differentiated and progress is concentrated in relatively harmless fields and disciplines. Most likely, regional blocs of interconnected and partially integrated open access infrastructures will develop, that may limit access to actors within their geographical sphere. Ties between researchers and organisations create strong links between EU and US repositories and research data platforms. China will likely draw the short end of the stick in this scenario.

Governments assume more of a proactive role in this scenario and open access therefore becomes less dependent upon the academic publishing business. Public policy supports initiatives from research communities and learned societies to develop alternative online platforms for publishing, reviewing, ranking and accessing research papers. Using these outlets, publishing will become less costly and time consuming for researchers. Traditional high-impact journal titles gradually lose their position and function. Gold route open access journals will play less important roles. Alternative publication platforms, services such as Unpaywall and initiatives flowing from the European Framework Programs will become more important. This opens up possibilities for alternative metrics, creating more incentives for researchers to publish on these new platforms.

Each focussing upon their own regional data infrastructures, governments in the United States and China invest heavily in research data services. Given the weight and urgency of societal challenges and the crucial role of science in tackling these, governments do not leave the development of the necessary data infrastructures and handling capacity to private, possibly foreign big tech firms.

Collaboration with non-academic partners intensifies and is predominantly local. As international trade and global production chains have come under pressure due to geopolitical controversies, business has become more regional, as have civil society organisations. The orientation of research on societal missions facilitates collaboration with both public and private partners. However, given the degree of global conflict, most of the collaboration will occur within national boundaries. Although there is a significant rise in citizen engagement in science, in the USA in particular, there are no generally accepted standards yet for citizen science or for democratising agenda setting in science.

Consequently, we observe substantial progress towards open science, certainly in the United States, and maybe also in China. This is organised within regional scientific ecosystems. Governments stimulate open science via research funding requirements. Moreover, they actively support the development of repositories and data infrastructures. As academic research is much more oriented towards resolving joint global challenges than towards business innovation, openness and sharing of data, resources and results has become the norm. Similarly, global challenges require massive coordination and collaboration within research communities. In this scenario, science has a mission that aligns very well with, and even requires, this openness and sharing.

2.4 Prosperity

Top/right: low geopolitical tension – more cooperation and mission orientation.

This is a world of relative harmony, where governments agree upon a common agenda to address global societal challenges. These shared ambitions create unprecedented opportunities for global coordination. Whereas in the *Missions* scenario distrust and security concerns overshadow international relations and incite caution and restraint, we here have conditions that allow a radical overhaul of the organisational paradigm of science. To, such a degree that Europe, the United States and China jointly embark on a route to unconditional openness and collaboration to the benefit of global prosperity.

Drivers and barriers:

- Awareness, information and knowledge +
- Incentives and disincentives for researchers +
- Framework conditions, system adaptations and investments in skills +

Governments and research funders demanding open access publishing have become a worldwide standard. Budgets to cover article processing charges are an integral part of research grants. More and more diverse platforms for open access will be developed for research papers in various languages. Moreover, for books and other research outputs. The position of large academic publishers has dwindled, as digital platforms managed by research communities and learned societies have taken over their functions of quality control, indicating academic importance, facilitating access provision and distribution. Open peer review has become common practise. Hybrid open access journals have vanished and full gold open access journals are losing terrain. Repositories, alternative publication platforms, data platforms and related services are increasingly integrated and interconnected worldwide, facilitating global open science. A distributed open digital research infrastructure is gradually being built. Because of the decrease in legal uncertainties and increased interoperability of ‘green’ repositories, costs and time of open access publishing have dwindled. Services such as Unpaywall, Sherpa/Romeo and OpenDOAJ, together with a growing uniformity in publication processes and rules make open access publication processes even easier. Citations and impact factors have become less prominent as metrics, because a wider range of research skills is now well recognised. For these, new metrics have been developed that utilise the greatly expanded access to meta-data.

In this scenario, all drivers help open science to flourish. International political cooperation facilitates the free exchange of research data and the interlinking of all sorts of open data clouds and networks. Thanks to favourable conditions, open collaboration has increased a lot, both in China and the USA. In fact, the world has moved towards an new paradigm for the organisation of science: collaboration, coordinated by using global digital information platforms has become the norm. For most academic researchers, frequent and intensive collaboration with non-academic partners has become a self-evident part of their work. Given generally congenial international relationships, open collaboration takes place regardless of national borders, supported by digital technologies. Language is no longer a barrier, thanks to advanced translation tools. Citizen science has become mainstream in the United States, since citizen engagement is experienced as a key to generating societal value with science. In China it is also becoming more popular.

Thus we here see open science being developed to its full potential. Not only is open science internalised as part of scientific culture and researcher’s habits, it is also stimulated and rewarded by public policies. Furthermore, it is required by research funders and publishing platforms and engrained in human resource management practices throughout the academic world.

EUROPEAN OPEN SCIENCE POLICY STRATEGIES AND THEIR EFFECTS

1 Four policy strategies for Europe and their effects

In this chapter we elaborate the European policy strategies that can be expected in the four scenarios presented in the previous chapter. Given the predicted developments with regard to open science in the United States and China and assuming a particular strategic goal of science policy in each scenario, we specify how the EU will react in order to achieve this strategic goal. The diagram below summarises our analysis. For each scenario it lists the strategic goals of science, technology and innovation policies more generally ('what') and the science policy instruments to achieve these goals ('how'), including the main policy interventions for open science in particular.

Summary: four distinct strategies	
Missions ***What***: grand societal challenges, socio-economic system development ***How***: New institutional and governance arrangements, massive public investments ***Science policies***: mission-oriented programming, incentivising cooperation ***Open science***: European infrastructures and platforms, incentives to collaborate and share	**Prosperity** ***What***: European position and role, freedom, cultural diversity ***How***: Specialisation: backing winners, selective investments ***Science policies***: absorptive capacities, sustainable ecosystem development ***Open science***: global infrastructures and platforms, global programming and collaboration
Defence ***What***: sovereignty, strategic autonomy, economic and technological self-sufficiency ***How***: Common markets for goods, services and labour, joint foreign and defence policies ***Science policies***: reducing dependences, security concerns, defence oriented ***Open science***: caution, low key, internally orientated	**Growth** ***What***: competitiveness, innovation ***How***: Industrial policies: credit, public procurement, taxes and subsidies, regulation, 'top sectors', innovation ***Science policies***: business inspired, innovation relevant, key technologies ***Open science***: public private partnerships, collaboration with businesses

Below, we describe the broader policy goals for each scenario and the strategies that could be expected from the European Union. We assume that these generic policy strategies set the stage for science policies in general and open science policies specifically. For the European policy strategies in each scenario, we specify expected impacts on the productivity, quality and societal impact of science.

1.1 Defence

Bottom/left: high geopolitical tension – competition as the principal mechanism of coordination.

<u>European strategies</u>

As geopolitical tensions mount and competition in the world intensifies, particularly between the US and China, who both aspire to global dominance, European policies generally take on a defensive nature. Sovereignty, strategic autonomy and economic and technological self-sufficiency are policy goals that are increasingly emphasised by politicians and policy-makers and that affect numerous policy areas. It is widely felt in Europe that European defence capabilities should be able to stand on their own feet and that European businesses should become world-leading, nurtured by strong competition in a sophisticated and unified European home market and sourcing from European scientific and technological resources. European science policy is subordinated to these general goals and open science policy is part and parcel of this broader policy effort.

Pitted against the large publishing and data service businesses in the US and China, it is clear that European publicly supported initiatives to maintain an open cloud service for scientific papers and data cannot match private services from the US, neither technically, nor in data and service quality. Thus Europe faces the choice between massively stepping up efforts and investments in its own publishing and data sharing infrastructure, or compromising on open access and open data.

Effects on productivity, quality and societal impact of science

Insisting on researchers sticking to open access implies that Europe pays for both journal subscriptions and article processing charges. Consequently, European science faces relatively high costs for publishing and reading. Moreover, as the EU shares its research results for free, whereas the rest of the world restricts access, European science is progressively disadvantaged, not only because of extra costs, but also in terms of speed of access.

Likewise, if the rest of the world does not share research data and Europe follows an open data policy, European research organisations incur high costs for mainly US data services and face more restrictions in using these data, whereas American and Chinese researchers readily access and use European data. Consequently, this lack of reciprocity and the dearth of a level playing field puts European science at a disadvantage. This may put a strain on productivity and quality.

However, such a paradigmatic change in the European organisation of science might induce secondary effects that may benefit the quality of European science. As a consequence of European open access policies, publications from Europe do not necessarily appear in the most prestigious journals. Nonetheless, they are widely distributed. Moreover, they are frequently cited and European researchers receive more feedback from peers. As European data are widely available, they are used and reused, both in Europe and in the United States and China. This facilitates more replication and feedback on European research. In addition, it improves the reliability of European science and adds to its reputation. It helps to flip the traditional reward system in science.

Geopolitical strife induces the US and Chinese governments to declare more and more research ‘strategic’ (and thus not to be shared indiscriminately) and to discourage international collaboration. This in itself stimulates EU member states to join forces and to reinforce within EU cooperation in science. Research budgets are increasingly concentrated at the European level, the European Research Area (ERA) is strengthened and the European Research Council (ERC) gradually dominates national research councils.

If Europe wants to adhere to a policy of open collaboration, it will be restricted to collaboration within Europe. Collaboration in research with non-academic partners, in particular with businesses, is stepped up to strengthen European defence capabilities. It is deemed important to reduce dependence on foreign resources and to prop up economic and technological autonomy. Hence, the societal impact of European science will be concentrated in domestic industries, in particular in defence and high-tech.

Maintaining an open science climate despite geopolitical tensions would make Europe an attractive region for many researchers from abroad, but they are discouraged by their national governments to work in Europe. An option for them would be to migrate permanently, which few researchers will do.

1.2 Growth

Bottom/right: geopolitical harmony – competition as the principal mechanism of coordination.

European strategies

International businesses originating in the US and China, taking advantage of vast domestic markets and backed up by deep pockets, flood Europe with innovative goods and services. Faced with such economic frenzy, European science, technology and innovation policies are completely subordinated to efforts to ramp up European economic prowess and to keep European businesses afloat. Economic growth is the overriding policy goal and public research is more than ever expected to contribute to this.

As China overtakes the US as the main residence of global companies, as home base of the largest science system in the world and of its principal source of innovation, it attracts lots of talent and investments from abroad. A brain drain from Europe and the US to China is gaining momentum. With great pains, the US manages to keep up with China in various, notably defence related, industries, at least in the short term. Europe is in danger of trailing further and further behind.

European open science policies are conceived as main elements in a broader policy package intended to support key industries. Science policy has become part of modern industrial policy. In this context, opening up scientific research mainly means opening it up to business interests. Research agendas are set in consultation with industry representatives, particularly in STEM-disciplines. Research programs are executed in close cooperation with companies and are financed jointly by public and private sources. Universities and businesses share research data, equipment and facilities on a grand scale. Together they invest in large scale research outlays and laboratory facilities. There is an unprecedented increase of researcher mobility back and forth between academic and business R&D. In this way, large chunks of the public research budget are geared toward supporting private sector innovation.

This close cooperation between public policy-makers and business does not preclude policy efforts to reign in the power of commercial interests over scientific publications and data. Europe deems it necessary to take firm steps to reverse the growing dependence of science on the information handling capacities of a few monopolistic big tech companies.

Effects on productivity, quality and societal impact of science

In this regime, open science in Europe is very open, however, only in a qualified sense. Research results and data are shared intensively with all kinds of stakeholders outside of academia, but just not with anybody. The strategic considerations and economic incentives to monopolise information and knowledge are just too strong to allow all papers and data to be easily dispersed into the public domain. However, European open science policy makes great strides in aligning public and private agendas. Moreover, it takes step to connect and integrate fundamental and applied research. Furthermore, it facilitates knowledge exchange between universities, research institutes and companies and establishes thriving networks of producers and users of technologies, in opening up academic career paths for researchers from an applied research background. Open collaboration is thriving as never before, albeit with selected partners in strategic partnerships. The collaboration with foreign industrial partners can pose a threat to the quality and credibility of public science though, because it largely takes place in exclusive partnerships beyond the reach of academic quality control mechanisms.

The overall effects of intensified competition on the productivity and quality of science are mixed. Although competition fosters creativity and invention, it also leads to fragmentation and duplication. Thus, open collaboration does not lead to genuine public open access to research outputs. Competition also drives up the amounts of funding needed to retain top class researchers, who constantly feel the lure of attractive contracts in the United States or China. International mobility of the best researchers counteracts efforts to exploit European research findings first and foremost in European businesses. The dominance of business interests in agenda setting and programming lead to more emphasis on and funding for STEM-research.

1.3 Missions

Top/left: high geopolitical tension – more cooperation and mission orientation.

<u>European strategies</u>

An accumulation of interconnected crises in the domains of health, economics and climate has stirred up popular dissent in the US and Europe to such an extent, that political circles have become convinced that profound changes are unavoidable. The urgency of simultaneously addressing the threats of climate change, economic instability and insecurity and further pandemics has emboldened the political resolve to overhaul traditional institutions and entrenched relationships between public and private actors. It has strengthened the determination to put the government more in control. Public authorities restructure industrial policies, labour market policies and tax regimes. Moreover, they employ science, technology and innovation policies to serve a limited set of well-defined public missions.

After decades of relative neglect of the issues, the main thrust of European and US science policy has become to ward off disaster resulting from global warming and loss of biodiversity. Open access to research results and open sharing of research data are considered vital to speeding up the required research processes and increase their efficiency. Unfortunately, the world has become entangled in a systems competition of sorts between the US on the one hand and China on the other. International relationships are tense, if not frosty. This puts a break on movements toward radical open science. A constant fear looms over European and US research and development of giving too much knowledge and technologies away, and being dominated economically and politically by China in return.

Consequently, European governments try to balance openness with restraint. European research funders demand open access and open data as a default. They also require researchers to acknowledge and document data sources in their publications and to give credit to the collectors and curators of these sources. Universities integrate this into their reward systems, thereby enabling careers based upon collecting, curating and sharing scientific data. Europe leads the way in elaborating detailed plans to build an open science cloud, to train large numbers of data stewards and to develop sufficient data curation capacity. The United States follows suit and threatens to overtake Europe, while China embarks on a similar development path.

There is a good basis to step up research collaboration aimed at dealing with grand societal challenges, in tandem with the US. There is a shared awareness that time is running out to deal with issues like climate change and energy. This underpins the political resolve to invest heavily in joint programming and research collaboration. But China is suspiciously regarded as an opportunistic competitor on the global scene, only to be approached with caution. This prevents a much needed fundamental reconfiguration of global science, possibly putting the solution to current crises in jeopardy.

<u>Effects on productivity, quality and societal impact of science</u>

The sheer fact that science is mobilised by the EU, with the support of European governments, as a main instrument to accomplish a number of public missions has given European science a massive boost. More consensus about a common agenda, more coordination and more collaboration have positive effects on the productivity of European research and on its quality. Openness and transparency reinforce these effects. The substantial public investments in open science infrastructures for the curation and exchange of publications, as well as data and other research intermediaries, help to speed up research processes and to monitor and certify their quality and integrity.

As tensions between China and the west persist and international relationships remain fraught with suspicion, researchers and research funders concentrate on local and regional agendas, rather than global issues. The European Green Deal and its successors focus first and foremost on addressing European grand challenges, thereby solidifying the common market and promoting further European integration in the face of a hostile world.

1.4 Prosperity

Top/right: low geopolitical tension – more cooperation and mission orientation.

<u>European strategies</u>

Large parts of global science assume traits of a giant man-on-the-moon project, in order to address an impending climate catastrophe. Intense cooperation has taken Chinese and American research to new levels and has established open science as a new worldwide standard. The main challenge for Europe in general, and for European science in particular, has now become to keep up with the leading blocks. This implies maintaining close connections to global networks, fostering absorptive capacities and simultaneously developing carefully selected unique key competences in areas of strategic importance. This holds for business and innovation as well as for technology and science. Only by developing a distinctive profile, Europe can ensure to be an attractive – and sometimes even an indispensable – partner in a global context.

In a world characterised by a radically open science, fostering absorptive capacity is of key importance. This will be a main focus of European science policy. It entails developing infrastructures and platforms to make information accessible and usable. These infrastructures and platforms help to make information searchable and findable, to structure and to grade information according to characteristics and qualities. A risk in this world is that big tech companies take the lead in making scientific outputs more accessible through providing comprehensive search engines. While content remains free, visibility of research output might become dependent on commercial algorithms or payment to be included and/or promoted in search engines.

European science policies aimed at absorptive capacities also include policies stimulating researcher mobility, both outward and inward. There is a continuous risk that the best researchers move to the most prominent research centres in China or the US, so substantial investments in facilities and conditions in Europe are necessary to assure that migration proceeds both ways.

In an open global science system, next to maintaining broad absorptive capacities, some degree of specialisation is vital. To build a sustainable field of specialisation, it is not so much essential to cultivate a specific line of research, but to build a coherent ecosystem around such a field of enquiry and innovation. A sustainable specialised ecosystem is a system that cannot easily be copied or moved, due to the fact that it consists of a broad range of interrelated knots – public and private research organisations, supply chains, networks of businesses, financial institutions, public authorities – that are locally networked and geographically rooted. Open science policies stimulating open collaboration can play a part in nurturing such ecosystems.

<u>Effects on productivity, quality and societal impact of science</u>

Public initiative and international consensus have created preconditions for a transformation of the global organisational paradigm of academic research. Openness has become the norm. Research plans, resources and results are made publicly available as early as possible. Researchers are recognised and rewarded for sharing. This has induced a research practice that relies more on sharing of resources and results and on collaboration, and less on competition.

This systems transformation has a beneficial effect on the productivity of researchers and the quality of research. It also benefits the transmission of scientific progress to society. Research waste due to either excessive duplication or to disproportionate competitive pressures on researchers is being reduced. As both research protocols and documented data of published studies are publicly available, replication studies are being facilitated, increasing the reliability of scientific results. Having numerous data sets available vastly augments the opportunities to conduct meta-analyses. This likewise increases the reliability of science.

However, the radically open nature of the global science system, in combination with the position of China as the global scientific leading power, makes the European science system vulnerable. The size and the quality of the Chinese research system attracts a lot of investments from European companies and it also attracts a lot of talented researchers, at the expense of European universities.

2 Wrap up: the future of open science in Europe in view of the four scenarios

In the previous chapter, we have presented four possible directions that policies in general, and open science in particular, may take over the coming decade in the United States and China. In this chapter we have specified likely European policy responses in each of the four scenarios, and their effects on the productivity, the quality and the impact of European science. We have seen that open science policies meet different obstacles and challenges in each of the four scenarios and that they have different accents, functions and effects. Open science in every scenario is not a goal in itself, but is supposed to support the broader policy goals of defence and security, competitiveness and economic growth, sustainability and health, or general prosperity and cultural distinctiveness.

We conclude this report by returning to the visions and purposes that pundits and policy-makers had in mind when they set out on a road toward a more open science, and by contrasting this with the development of open science in each of the scenarios. Building on policy discussions and public consultations in preceding years, the European Commission published a vision on Open Science in 2016 (European Commission, 2016a, see also textbox below): "Open Science represents a new approach to the scientific process based on cooperative work and new ways of diffusing knowledge by using digital technologies and new collaborative tools. The idea captures a systemic change to the way science and research have been carried out for the last fifty years: shifting from the standard practices of publishing research results in scientific publications towards sharing and using all available knowledge at an earlier stage in the research process." The Commission states three aspirations of Open Science (ibid., p. 52):

- Making science better, by making it more credible and replicable, for example by addressing governance and scientific integrity;
- Making it more efficient, by avoiding duplication of resources and optimising the reusability of data;
- Making it more open, by improving the accessibility of data and knowledge at all stages of the research cycle, and enabling text and data mining by ensuring the appropriate conditions within copyright law.

A Vision of the Future

The year is 2030. Open Science has become a reality and is offering a whole range of new, unlimited opportunities for research and discovery worldwide. Scientists, citizens, publishers, research institutions, public and private research funders, students and education professionals as well as companies from around the globe are sharing an open, virtual environment, called The Lab.

Open source communities and scientists, publishing companies and the high-tech industry have pushed the EU and UNESCO to develop common open research standards, establishing a virtual learning gateway, offering free public access to all scientific data as well as to all publicly funded research.

The OECD as well as many countries from Africa, Asia, and Latin America have adopted these new standards, allowing users to share a common platform to exchange knowledge at a global scale.

High-tech start-ups and small public-private partnerships have spread across the globe to become the service providers of the new digital science learning network, empowering researchers, citizens, educators, innovators and students worldwide to share knowledge by using the best available technology.

Free and open, high quality and crowd-sourced science, focusing on the grand societal challenges of our time, shapes the daily life of a new generation of researchers.

European Commission (2016), Open Innovation, Open Science, Open to the World – a vision for Europe, p. 34.

Currently, UNESCO is finalising a Recommendation on Open Science, to be approved by Member States by the end of 2021. This promotes science as a common endeavour to the benefit of humanity as a whole. Scientific practices should meet the highest standards of quality and integrity. Scientific knowledge should be openly available and its benefits universally shared. Scientific research should embrace a diversity of knowledge, practices, outputs and topics and be inclusive, ensuring equity among researchers from developed and developing countries, enabling fair and reciprocal sharing of scientific inputs and outputs and equal access to scientific knowledge.

Set against these aspirations and ideals, it is clear that they contrast strongest with conditions in our *Defence* scenario, as they do not favour openness and sharing in science. In this scenario it will be very costly for the European Union to continue its policies for open access and open data, because the other regions will act as 'free riders'. Science as a joint human endeavour to the benefit of all people in the world is a very long way off. Science getting better, more efficient and more open is hard to achieve on a European scale. Having said this, an impetus for openness may nevertheless pay off in the longer term, since this could help to develop a sense of quality and efficiency in science that is not equalled in other regions. Moreover, stimulating open collaboration within the European Research Area would be a good investment.

Conditions in the *Growth* scenario are slightly more conducive to bringing the ideals of open science closer. Peaceful international relations help to collaborate internationally and, for instance, to effectively integrate research practices in developing countries into the global science system. However, as the world order remains basically market based and dominated by private initiative, open science faces significant barriers. Sharing is difficult to reconcile with competing and striving for profits. Open borders lead to a serious risk of brain drain, in particular by researchers moving to China. Investments in open science would catalyse this. In order to mitigate this problem, the EU could invest in better working conditions for researchers, for instance, by focussing on human-centred innovation.

The *Missions* scenario generally provides a fertile ground for the further development of open science in Europe. The main drawback here is the risk of fragmentation: every region choosing its own solutions for sharing data and publications. This implies that the EU will need to invest sufficiently in quality control, to make sure that data and publications from elsewhere are subject to an adequate review before being absorbed in Europe.

The *Prosperity* scenario aligns well with the current European and UNESCO ambitions regarding open science. It presents the best chances for a more value-driven science, responsive to global societal needs. It opens up possibilities to establish a unified global science system that is able to confront those pressing global challenges that are too encompassing to be resolved on a regional scale. The challenge here for Europe is to stick to its fundamental values and find its niches in a world of science dominated by China and the United States. Given the expected rise of the Chinese science system, strong openness can catalyse outward mobility of talented researchers and research funders. To mitigate this, Europe could further develop a number of distinctive, carefully selected knowledge ecosystems. And it should invest in its absorptive capacity.

Our analysis demonstrates that attaining the goals of open science poses different challenges under different circumstances. The costs and benefits of an open science policy differ across the four scenarios. Given the range of expected effects, there is no robust policy strategy that is preferable in each scenario. There are a couple of policy directions, however, that are bound to be productive in most of the scenarios, and will do little harm in others:

- Creation of a distinctive profile of European science, based on European public values.
- Coordination of investments in data standardisation and data curation capacity.
- Investment in quality control, to ascertain the quality of data or research findings from other regions.
- Further development and promotion of new ways to incentivise and reward researchers to contribute to open science.
- Stimulation of open collaboration with a diversity of non-scientific partners, both private and public.

The three aspects of open science as we have defined them in our scenarios come down to two key mechanisms: sharing and collaborating. Sharing means making scientific results, data and other inputs accessible to others; collaborating means working together and letting other actors, in particular from outside the scientific community, exert an influence on research agendas and research processes. Although they are both part of the open science agenda, there is potential tension between collaborating and sharing: some collaboration partners, especially industrial organisations, prefer a certain level of exclusive access to data and results. Europe promotes open science to improve science: to make science more reliable, more efficient and more accessible. Its current policies concentrate on sharing. Collaboration has also been promoted. However, most attention has been paid to cooperation with businesses and public authorities. It remains an open issue what strategies Europe could develop to improve science by stimulating open collaboration with societal partners and citizens.

Our scenario analysis of the future of open science has focused upon the interaction between Europe, the United States and China. We have thereby reduced the dynamics of global science to the strategies of its three most dominant players and have left the rest of the world out of the picture. In particular, we have not included important players like India and Japan, we have bypassed South America, where great strides have been made in open access, and we have not entailed developing nations in general. As described above, the chances of realising the global ambitions of the open science movement, to make the scientific endeavour truly inclusive and equitable, differ per scenario. What strategy Europe may employ to address cooperation in open science with the rest of the world, the developing world in particular, depends on geopolitical factors and the attention paid to societal challenges. Such a strategy, in line with the UNESCO Recommendation on open science and firmly anchored in European values, should prioritise inclusiveness and the responsiveness of science to the needs of the world.

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Open science proposes a fundamental systemic change in the way research is conducted, shared and evaluated. This foresight study considers how different levels and means of open science policy implementation in the United States and China could affect European opportunities to realise open science and have consequences for the European science system. Based on a review of drivers and barriers for open science, it explores four future scenarios, which vary in terms of geopolitical relationships and the dominant coordination mechanism. The report concludes with suggestions for European science policy to foster open science practice in different future circumstances.

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