INTERNATIONAL CO-OPERATION IN STI FOR GRAND CHALLENGES – DRAFT SYNTHESIS REPORT

This document is submitted as background for the High-Level Roundtable of the CSTP on "Creating Science, Technology and Innovation Policies for Society" on 4-5 April 2019.

Contacts:
Mario Cervantes; Tel: +33 1 45 24 94 31; Email: mario.cervantes@oecd.org
Soon Jeong Hong; Tel: +33 1 45 24 92 38; Email: soonjeong.hong@oecd.org
Teru Koide; Tel: +33 1 85 55 60 26; Email: teru.koide@oecd.org
Yilong Qu; Tel: +33 1 45 24 76 91; Email: yilong.qu@oecd.org.

OECD
BETTER POLICIES FOR BETTER LIVES

Foreword

This synthesis report presents the results of a study conducted by the Secretariat of the OECD's Committee for Scientific and Technological Policy. The Committee asked the Secretariat to study ways to improve the efficiency and effectiveness of government-sponsored international collaboration in science and technology to address grand challenges. The synthesis report draws on several analytical inputs[1], notably a background paper and the results of a joint CSTP-GSF workshop in Paris on 22 March 2017 [DSTI/STP(2017)10]. It also draws on a survey to CSTP policy makers to map the domain of international STI co-operation dedicated to grand challenges and whose results were presented to the CSTP in October 2017 [DSTI/STP(2017)13]. Two expert workshops were organised in 2018 to explore the barriers to international co-operation in more detail: one on designing multi-stakeholder partnerships in Moscow on 4-5 May 2018 and another in Seoul on 21-22 September 2018 on linking STI policies and Official Development Assistance (ODA) to address grand challenges.

The key message of this report is that current mechanisms for international co-operation in science and technology are unfit to tackle today's grand challenges. The international co-operation mechanisms in place favour basic research, the strengthening of national research systems as opposed to innovation systems and they have not been designed to specifically address grand challenges, especially in developing countries where the impacts are greatest. To make international STI collaboration more effective in this context, governments should re-assess their national STI strategies with a view to connecting them with international co-operation objectives; develop new funding instruments and partnerships and design new governance arrangements to connect national efforts with co-operation on the grand challenges. Today globalisation and technological change, not least the current wave of digitalisation; the changing nature of the scientific enterprise (e.g. data-driven science); and the emergence of new global players (e.g. BRICS countries) present new opportunities and challenges for international STI co-operation.

This report has three parts. The first part reviews the different forms of international co-operation in science and technology followed by recent trends in international STI co-operation in public research based on available data. The second part discusses the emergence of grand challenge discourses in international STI co-operation and highlights a set of policy issues that could help governments think more strategically and effectively about the way that they carry out international co-operation in science and technology. The third part explores the interconnections between ODA and international STI co-operation for grand challenges and the role of new "challenge funding mechanisms" and multi-stakeholder partnerships with developing countries. The annex provides case studies of challenge funding instruments and programmes based on desk research and country contributions.

[1] The Secretariat acknowledges the intellectual contributions from CSTP delegates and numerous experts, including Mr. Ian Hughes, Senior Research Fellow, University Cork.

Executive Summary: Key Findings

1. International co-operation in science, technology and innovation (STI) – as in other policy domains - is based on national interests, enabled by shared understanding and common values. This is an important principle to consider when discussing the contribution of international co-operation STI to address grand challenges.
2. A second principle borne out of the first is the principle of reciprocity that is central to relations between sovereign nation states. Reciprocity in scientific co-operation implies that co-operation should be mutually beneficial even if there may be asymmetries or equivalences in the capacity of research partners or developing countries to co-operate.
3. A third principle is that for countries to be able to co-operate in STI their national innovation systems must be strong. Consensus on the need for international co-operation remains fundamentally in the hands of the nation-state while the strength of ability to implement co-operation relies on strong research institutions such as ministries, funding councils, universities, and public research organisations as well as good governance arrangements.
4. These principles have guided international co-operation in science and technology since the post-World War II period. International STI co-operation has increased sharply as illustrated by co-publishing trends. Researchers, institutions and governments alike have benefited from international co-operation in STI. The United Kingdom's nuclear reactor programme benefited greatly from co-operation with France in the 1960s. Indeed, in the European context, the EU's Framework Programmes have contributed greatly to stimulating co-operation between nations in the EU as well as with countries outside.
5. Grand challenges are broadly defined as persistent, complex and large scale problems facing humanity that require science and technology to solve them because no single country can solve these problems alone (OECD, 2012, RAND, 2014). Many of these grand challenges are related to long-standing problems of human health; the environment; and a lack of economic development more generally. They require knowledge from many scientific disciplines and a range of government, private and civil society actors to pull human, financial and infrastructural resources to work together.

Fragmentation of international STI co-operation

6. Yet despite the obvious contribution that STI can bring to grand challenges, international collaboration in STI suffers from fragmentation, notably as regards the bottom-up national initiatives. This is even more so the case for the "grassroots" spontaneous initiatives of researchers themselves, which may actually face barriers to development (e.g. visas/work permits for researchers, and/or purely national grant schemes which do not allow financing of international projects)

7. International co-operation in science and technology also remains dominated by collaborations to advance basic research, and to a lesser extent, applied research. This is not to say that basic research is not important for the grand challenges. Without basic research, we would not have the Global Positioning System (GPS) that enables a range of innovation from mobile communications to digital farming in India and sub-Saharan Africa, but it is not sufficient in the face of the urgency of the grand challenges. Furthermore, the direction of international co-operation in research remains primarily driven by "bottom up" priorities of individual researchers, research organisations, even if a number of collaborations on climate change, global health, renewable energy or sustainable agriculture are initiated via "top down" processes.

8. Research funding agencies have a great deal of expertise in funding international collaborative projects that can promote research excellence in specific disciplines and areas but they are less well equipped to fund and organise collaboration to address grand challenges, especially involving developing countries. This is partly because of institutional missions that prioritise research excellence over other goals. In addition, mobilising STI to address grand challenges requires more than research funding; it requires more understanding markets and business innovation processes. It also requires investment in hard and soft infrastructures such as entrepreurial capacity to convert research findings into practical solutions.

9. Another major barrier to mobilising STI for grand challenges concerns the historical disconnect between policy communities responsible for promoting development through Official Development Assistance (ODA) and the mainstream science, technology and innovation policies. The development community, including multilateral aid agencies traditionally focused on helping developing countries improve primary education, reduce poverty and infant mortality and improve agricultural productivity. Advanced research capabilities, higher education and researcher training, and the use of frontier technologies were not priority areas for development aid agencies until fairly recently.

10. Indeed, many of the existing mechanisms for international STI co-operation date from the second half of the 20th century[2] and were designed for advancing basic research and applied research in particular fields. The amount of specific funding for international co-operation in science and technology represents only between 5 and 8% of national budgets in many European OECD countries according to Eurostat data[3].

11. And while countries have mainstreamed societal or grand challenge agendas in their domestic STI strategies and agendas, few of them link the corresponding national policies to international co-operation initiatives in these areas with the exception of climate and the environment. There is also the problem that OECD

---

[2] For example, the Consultative Group for International Agricultural Research (CIGIAR) was established in the 1970s.

3 This figure excludes Horizon 2020 funding since the Horizon 2020 funds come from the annual general budget of the EU allocated to it by member states. Therefore the funds which are used to fund H2020 are not counted as national budget funds for R&D even if they act as a catalyser and help leverage spending by national programmes. More information is available on the following Eurostat webpage. http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:R_%26_D_budget_statistics_-_transnationally_coordinated_research&oldid=42106

country priorities' for grand challenges are not shared on a global scale. For example, Alzheimer's have received priority attention from governments in OECD and a few non-member countries, but other global health challenges such as neglected tropical diseases that mainly affect a large number of developing countries, have received far less attention and funding. As little as, 1% of all funding for health R&D is allocated to most important health concerns of developing countries (WHO, 2017).

The present system of international STI co-operation is not well equipped to cope with the grand challenges faced by OECD and non-Member countries in the 21st century.

12. Stepping up efforts for OECD countries to co-operate in STI among themselves and especially with developing countries will require important changes to the current regime for international STI co-operation. Recently the EU has adopted an "Open to the World" policy with a view to expanding its co-operation with third countries. The UK has been at the forefront of efforts to increase research funding for ODA and many other countries have made this issue a priority.
13. In parallel to changes to international STI co-operation, there is also a need for changes in the way national innovation policies connect domestic objectives with the global challenges. Many countries have stepped up R&D investments in health and environment. Within the EU, framework programmes have helped link national objectives to Community-wide objectives in order to strengthen the creation of a European Research Area (ERA) and boost the region's research and economic systems. However many of grand challenges require co-operation outside EU and OECD countries. Indeed, despite the rise of the BRICs countries, international co-operation is concentrated within and among OECD countries.
14. Mission innovation policies could potentially offer an opportunity to link efforts on national challenges and competitive strengths with efforts to develop common solutions to shared challenges. However, mission-oriented innovation policies represent, a priori, a greater opportunity for international co-operation among countries with shared strengths than with developing countries who lag behind advanced countries in terms of both research capacity and innovation potential.
15. Better sharing of data on international STI co-operation between countries is needed. While data and information are generally shared - along common criteria such as reciprocity and shared cost principles, many research-oriented collaborations are uncoordinated on a global scale and much of the potential synergies from sharing costs or information are lost. A collaborative research project sponsored by one OECD country might be replicated by a similar project sponsored by another OECD country in the same or a neighbouring country. To reduce such fragmentation of international efforts, the co-ordination of national public research agendas oriented toward global challenges is essential.
16. Improved data on both international co-operative R&D projects and outcomes would greatly enhance the ability of decision makers to monitor and evaluate these activities. There is considerable potential to build on successful experiences to date to develop a more co-ordinated and effective international approach to the sharing of research project information in many fields of science.

Co-operating not just for science and economic growth but for global public goods

17. Innovation for grand challenges requires that policymakers adopt a broader view of the benefits of international cooperation that include not only economic benefits but also public good benefits and benefits in terms of facilitating system transitions to achieve national sustainability and inclusiveness goals. Policymakers also need to adopt a longer period in evaluating the impacts of innovation for grand challenges. The rationale for international co-operation in STI for grand challenges is five-fold.

    - There are limited incentives for individual countries to provide the public-good solutions that are necessary;
    - Providing comprehensive solutions for the global and interconnected problems associated with grand challenges exceeds the capacity of single states or market forces alone;
    - Concerted co-operation is essential to deliver solutions in acceptable timeframes to avoid approaching environmental tipping points or severe societal crises;
    - There are major problems in the scale of investment that is necessary;
    - There are serious issues of technological uncertainty that require multiple search paths to be explored, which means there will inevitably be a few successes and many failures.

18. There must therefore be collective arrangements for the distribution of direct costs and private benefits that may accrue. The increasingly globalised nature of innovation provides an additional rationale for international co-operation in STI for grand challenges. While in some cases, innovation may be reducible to specific territorial contexts, the geographical configuration of innovation systems has become increasingly complex, spanning actor networks and institutional contexts across borders.

19. Thus, for example, the ongoing transition to renewable energy in Germany, China and the UK can be framed not solely because of national innovation initiatives in each of these countries, but rather as a co-evolutionary dynamic between innovation actors in all these places that together form a new emerging global innovation system (Feunfschilling and Binz, 2017). These findings suggest that the ability of countries to meet their own national challenges can be strengthened by international co-operation.

From Competition to Co-operation

20. The success of international co-operation will in turn require a transition from competition to co-operation as the underlying principle informing innovation policy and behaviour.

21. Innovation policy globally is dominated by the “national innovation system” model that aims to strengthen and enhance the productivity of existing innovation systems within national boundaries. It is based on a competitiveness framework whereby countries compete for competitive advantage by attracting investment, enhancing human capital and engaging in competitive innovation to

deliver economic benefits in terms of jobs, exports and growth. This competitiveness framework has advantages in terms of increasing productivity and encouraging innovation. It is only possible, however, because the problem that NIS policies address, namely the efficiency of the national innovation system, can be addressed largely by individual nations.

22. Innovation for grand challenges however needs to address problems that individual countries cannot solve acting alone and solutions are needed urgently if we are to avert severe environmental and societal consequences. Competition under such circumstances must be balanced with co-operation in order to pool expertise, reduce duplication of effort and waste of resources, and find solutions within periods commensurate with the threat.

New forms of funding and partnerships are needed for STI in grand challenges

23. The grand challenges, because of their complex, open ended and unpredictable nature, forces STI policy makers to reflect on how to combine national objectives and global public goods. Traditional government led approaches to international STI co-operation however will not be sufficient to combine these goals. This will require increased co-operation and new forms of co-operation – across borders, across disciplines and between researchers, firms, governments and civil society.

24. Such new funding models including so called "grand challenge funds" such as the UK's Global Challenge Fund or Denmark Danish Solutions Fund which aim to promote excellence in national research system by fostering development research and building research capacity in developing countries. Similarly, the Norwegian Research Councils' NORGLOBAL2 specifically targets health in low- and lower-middle income countries. Nevertheless, in the grand scheme of things, these funds range from the hundred millions Euros to the low billions with periods ranging from 5 years to 10 years.

25. Multi-stakeholder collaborations that bring together previously excluded groups, such as frugal and low-tech innovators with digital entrepreneurs can foster new types of innovations that dominant actors alone would not create, and help ensure that the innovations created are widely acceptable and can diffuse more rapidly in society. Innovation policies can also support the deployment of appropriate technologies that address problems at a local level.

Importance of collaborations for innovation including developing countries

26. Strengthening national innovation systems and building sustainable sociotechnical systems in developing countries will be necessary to achieve global environmental sustainability as set out in the Paris Agreement and achieve the broader sustainable development goals set out in Agenda 2030. From the perspective of grand challenges, innovation is not the preserve of advanced economies but is a crucial part of the technological change and development needed in all developing countries. As the national innovation systems of developed countries attest, any well-functioning NIS needs to be connected internationally to enable the flow and development of knowledge, skills and innovation (Ockwell, D. and Byrne, R., 2016).

27. Financial support for technology transfer to developing countries will therefore have limited impact on environmental or broader sustainable development goals unless complimentary policies aimed at strengthening capacities within developing countries are also in place.

28. Developing countries need both absorptive and creative capacities and be able to develop their own adapted technologies and solutions based on indigenous knowledge. In this context, international co-operation in STI for the grand challenges is necessary to strengthen local capacities and accelerate the global transitions to sustainable development and environmental sustainability.

29. In conclusion, the CSTP project on international co-operation for grand challenges has identified some policy issues that that need to be addressed to promote international co-operation in today's environment.

- **Need to link national research agendas and international priorities**. Grand challenges are both local and global. International strategies cannot be set indiscriminately from national research agendas and the grand challenges. Many countries such as Japan, Brazil and France are now seeking to align their national and international STI strategies with the Sustainable Development Goals for example. This implies new governance structures to enable cross-ministerial collaboration as we as effective interfaces between line ministries, development aid agencies, and trade and foreign ministries.

- **Multi-actor STI collaboration is needed**. Whereas traditional scientific collaboration involved collaboration among scientific organisations or between governments (i.e. via bilateral and multi-lateral agreements) global challenges require engagement with a broader range stakeholders including companies, charities, foundations and civil society groups that can produce knowledge and apply technological solutions locally and globally.

- **Liking STI policies more closely to ODA** (Official Development Assistance). While international research collaboration through ODA activities has increased in some countries such as the Germany, Japan, United Kingdom, and the United States, total financing for research and technology in the context of ODA remains marginal in absolute terms (around 5% according to OECD estimates). Improving investments in STI-related ODA -as well its measurement in line with global standards – should be an important element in national efforts to address the grand challenges through international STI co-operation.

- **International STI collaboration should be designed to take into account interdependencies** between the various grand challenges and potential policy trade-offs. It also implies participating governments, funding agencies and partners, need to ensure greater interdisciplinary in the scientific collaboration projects.

- **International research infrastructures should not only advance scientific knowledge but they should promote innovation for the grand challenges.** This implies ensuring the knowledge and publicly funded data from such research infrastructures can be diffused more broadly to the local research communities and firms, enabling them to innovate and apply appropriate technologies to local problems.

- **Differences in the regulatory environments and rules regarding researcher mobility and IPRs** can nonetheless create barriers to international STI co-operation for the grand challenges just as they do in the case of international scientific collaborations.
- **Wider range of impact indicators are needed** to measure the impact of international STI co-operation for the grand challenges. Traditional, research excellence dominates the indicator for international STI collaboration. Societal, environmental and human resource impacts will also need to be integrated into impact assessment.

International co-operation in science and technology: A primer

1.2. Introduction

30. International co-operation in science, technology and innovation (ST) is increasingly driven by various push and pull factors such as global competition, limits on national research funds and the need to share costs as well as data in some fields. International co-operation in STI is, however, a multifaceted phenomenon. Some facets such as the internationalisation of public research, the internationalisation of universities, the international mobility of researchers or the globalisation of business R&D have been the subject of much study[4]. One aspect that has been less studied is the issue of how governments and the various actors involved (ministries, national research funding councils, public research organisations, universities, national labs, etc.) effectively prioritise, finance and implement international STI collaboration with the explicit objective of addressing the grand challenges.

Table 1. Main categories of international STI collaboration mechanisms

Type of research	Individual scientists	National performing Institutions (e.g universities & PROs, national labs)	Dedicated Research funding via ODA ("Development Research")	Global Challenge Research Funds	Bilateral and Inter-governmental initiatives (Horizon Europe)	European Research Council Grants	International Networks of Research Funders & Performers (CGIAR)	International scientific organisations (CERN, ITER)	International organisations with STI mandates (IEA,NEA WHO, IPCC)
Basic Research	X	X			X	X		X	
Applied Research		X	X	X	X		X		X
Bottom- Up	X				X	X			
Top-Down		X	X	X	X		X	X	X
Supply-led	X	X	X		X	X	X	X	X
Demand-led		X	X	X	X				

Source: OECD elaboration.

31. Science, technology and innovation are, by and large, national activities but they also have a long history of internationalisation. As illustrated in Table 1, the landscape for international co-operation in science and technology involving national governments and public sector actors is the varied and diverse. International co-operation in STI can be understood as all "co-operative relationships between STI performers in non-equity relationships" (Schwaag and Remoe, 2014[1])

32. **International co-operation by scientists, universities, and public research organisations** takes place mainly through the initiative of individual scientists and institutions. This mainly scientific collaboration has both top-down and bottom-up elements which follow more informal and self-organising modes of co-operation (Junkers

[4] The internationalisation of business R&D and international co-operation between businesses themselves is outside the scope of this paper, even if business is an essential partner for financing and implementing STI solutions to address the grand challenges. Past CSTP work has explored the internationalisation of public and private R&D while recent work by the OECD Committee of Industry, Innovation and Entrepreneurship (CIIE) has explored the R&D offshoring of multinational firms.

and Cruz, 2010[2]); (Wagner and Leydesdorff, 2005[3]). Indeed, the open culture and structure of the scientific community - notably it openness to review from "peers" whether these be from learned societies at home or from abroad – has long been conducive to international co-operation. Individual researchers regularly exchange regularly through information networks and international symposia. The informal networks of researchers play a recognized role in the creation of knowledge, its diffusion as well as its quality. Such networks can span both basic research and innovation such as "inventor networks" involving inventors, entrepreneurs and venture capitalists.

33. **The international co-operation activities of universities and public research organisations** also takes various forms. Pfotenhauer et. al., (2016) in their study of the global partnerships of the Massachusetts Institute of Technology (MIT) identify four architectures that characterise international co-operation by universities: bilateral, networked, institution building and functional expansion. Universities may establish co-operation activities with other universities in foreign countries directly or via co-operation with a foreign government. In the latter case, the internationalisation strategy of the institution is an important driver. Sometimes the national government strategy is driver itself or the government plays a facilitating role through "science diplomacy" objectives. Canada, Finland, Germany and Ireland have adopted international education strategies to promote national colleges and universities abroad. Many universities and public research institutions have established centres abroad. Examples include the Sino-Danish Centre for Education and Research, Germany's Max Planck Centres in seven countries and Fraunhofer Centres in six countries, and France's Institut Pasteur in Korea.

34. **Inter-governmental co-operation through the bilateral and multilateral agreements among governments** and or between governments and public research organisations. Depending on the institutional arrangements, the focus can be basic or applied research. Within the EU, international co-operation in STI mainly focuses on applied research through the Framework programmes with the goal of reinforcing areas of scientific and technological strength that can enhance the EU's economic competitiveness and secondly, as capacity building tool by enhancing the quality of STI in catching-up EU economies. In contrast, the European Research Council grants support international collaboration in basic research based on scientific excellence criteria.

35. **At the level of bilateral co-operation,** international co-operation between two countries can take the form of joint research programmes and centres (e.g. US-China Clean Energy programme), specialised international centres of excellence, interdisciplinary centres, and research networks and platforms on specific areas (e.g. Molecular Biology). In practice, many of these centres and platforms may be located in or centred on universities or public research organisations (PROs). The type of institution matters for operationalising co-operation. Twenty-nine percent of the total ODA budget in France is delivered through higher educations and public research institutes.

36. **International organisations that are mission or mandate-oriented** is another category of institutionalised multi-lateral co-operation. Examples include World Health Organisation, the International Energy Agency and the climate (IPCC). The IEA has a mandate to promote international collaboration in the area of renewable energy and energy efficiency and supports various networks with this aim, including the "Clean Energy Ministerial"- a regular meeting of high-level officials responsible for promoting clean energy.

37. **International scientific organisations** are yet another category of institutionalised co-operation to support joint research, especially in areas of basic research such as physics, mathematics, and astronomy.

38. **International co-operation via formal networks of research institutes** in certain research fields and missions. Examples include the Consultative Group for International Agricultural Research (GIGIAR) and the Global Network for Neglected Tropical Diseases established in 2006. This later network brings together independent and disease-specific organisations for the purpose of co-ordinating their efforts in disease intervention and in developing a new generation of improved control tools. More recently, the Belmont Forum brings together funding organisations, international science councils, and regional consortia in research partnerships based on competitive calls involving scientists and stakeholders from at least three countries. The Future Earth Initiative federates research projects and other initiatives related to global environmental change.

Table 2. Examples of international STI collaboration mechanisms

Global Challenge Research Funds	
Canada Grand Challenge Fund	Project grants for innovation
UK Global Challenge Research Fund	Project grants for public research
Newton Fund	Project grants for public research
IFD Grand Solutions Programme – Denmark	Project grants for public research
Norway Global Partner (NORGLOBAL)	Project and programme funding
International Scientific Organisations/Infrastructures	
CERN	Fundamental Research institution
International Thermonuclear Experimental Reactor (ITER)	Fusion research institution
Intergovernmental Oceanographic Commission (IOC) of UNESCO	Science advise and planning support
Intergovernmental organisations with a STI mandate/Mission	
International Energy Agency (IEA) , Mission Innovation, Clean Energy Ministerial	Technology agreements
EU Cost	Promote research networks
World Health Organisation	Applied research
Bilateral R&D centres/programmes	
Department of Energy US.-China Clean Energy Research Center; US.-India Energy Cooperation Initiative	Institutional funding for targeted research
International research funding programmes	
EU Horizon Europe	Project research grants for societal challenges
EU Joint Programming Initiatives(JPI)	National co-funding for specific grand challenges (e.g. Oceans research, Alzheimer's research)
NIH Grand Challenges in Global Mental Health Initiative NIH Grand Challenge in Chronic Non-communicable Diseases.	Research grants involving research in developing countries
International research networks and platforms	
CGIAR	Research centres
African Network for Drugs and Diagnostics Innovation (ANDI)	Promote Health Product Innovation
Future Earth	Virtual research centres
Group on Earth Observations (GEO)	Research centres
Wellcome Trust Centres for Global Health Research (WTCGHR)	Research centres
Development Co-operation Research (ODA) Funding Programmes	
Japan SATREPS	Education and research grants
Korea S&T Official Development Assistance Funding	Project grants for development research
r4d - Swiss Programme for Research on Global Issues for Development	Project grants for development research
National Science Foundation Partnerships for International Research and Education (PIRE)	Project grants to host foreign researchers
Unite States National Institutes of Health (NIH) - Brain Disorders in the Developing World: Research Across the Lifespan (BRAIN)	Project grants
Development Research Institutes/Centres	
International Development Research Canada (IDRC)	Institutional funding for development research
The Research Institute for Development(IRD)	Institutional funding for development research
The Center for International Cooperation in Agricultural Research for Development(CIRAD)	Institutional funding for development research
German Regional Centres in Southern and Western Africa.	Co-ordination the activities of different ministries and government agencies

Source: OECD STIP Compass Database; national sources.

39. **International research infrastructures** are another facet of the international co-operation in public research. Governments invest in global research infrastructures principally to advance knowledge and to share the costs that exceed those that can be borne by a single country or institution or when the research challenge is shared by a large number of actors/countries. Moreover, investment in international R&D infrastructure is essential to attract international flows of R&D, human resources, and generate spill overs to local economies and high value-added activities. Among other advantages, the fruits of such investments are somewhat less internationally mobile than are the results of technology development programmes supported by public funds – indeed, there are strong and lasting regional agglomerations of technological expertise and economic impacts. Collaboration between OECD countries on large research infrastructures is also a means for engaging in longer-term co-operation that could have both public and private returns.

40. Increasingly emerging economies countries are participating in the development of large-scale infrastructures such as the Square Kilometre Array (SKA) that is a global project co-located in Australia and South Africa. India for its part collaborates with the EU's International Thermonuclear Experimental Reactor (ITER).

41. Whilst the majority of research infrastructures are focused on basic science, there are some, particularly in the environmental data and services areas, that are essential for applied research to address grand challenges. Increasingly and partly related to the move towards more open and data-driven science, international distributed research infrastructures have become more prevalent and have increased demands for international co-ordination and co-operation. Another issue is how to open up the large infrastructures to more open and inclusive international co-operation of scientists from different disciplines. Visiting scientist programmes is one way but more importantly is providing access to general-purpose observations and data could further stimulate larger numbers of researchers globally.

1.3. Section Summary

42. This section has provided an introduction into the complexity and multifaceted nature of international co-operation in science and technology. International co-operation in science and technology remains characterised by mechanisms to advance basic research and applied research priorities. Indeed, many of the existing mechanisms for international STI co-operation date from the second half of the 20th century. Some specific mechanisms for co-operation for the grand challenges have emerged in the 2000s. A typical feature is the strong focus on demand-driven processes for problem formulation and implementation; a combination of different delivery instrument to address a societal challenge. However, such programmes also differ in size, governance approaches and focus on developing countries by level of development or geographic region (see Annex Table 1 for comparison of the funds according to their objectives, funding and priority setting and governance arrangements).

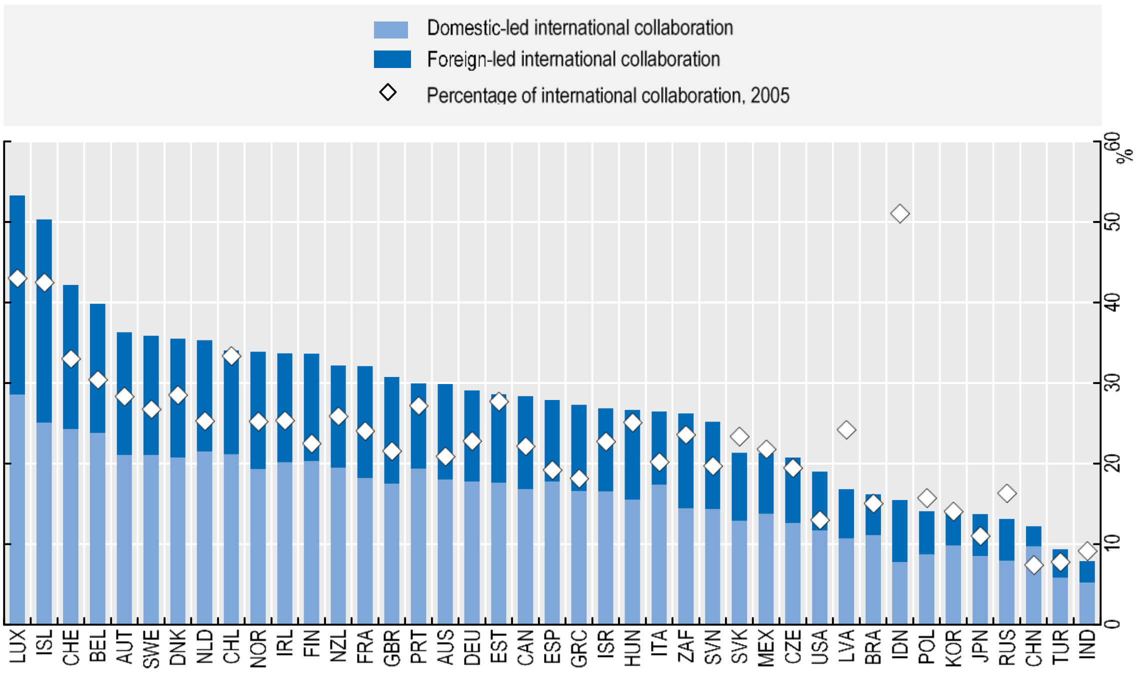
International co-operation in STI in increasing and expanding

43. By many measures or indicators, international co-operation is increasing and expanding globally. This raises opportunities for research actors to work together to find solutions to global challenges. Emerging economies such as Brazil, China, Russia and South Africa are important players in STI, widening the networks for international co-operation. However, international co-operation patterns are rather stable because international co-operation takes time to develop. The success of the BRICS countries in increasing collaboration has a lot to do with earlier investments in their national research systems, including human capital. Smaller countries are also relatively more prone to engage in international co-operation given the limited size of their national research systems.

International co-publication trends

44. Over the 2005-15 period, international collaboration on scientific research intensified on a worldwide scale. China almost doubled its collaboration rate, albeit from a very low base. In 2015, Luxembourg, Iceland, Switzerland and Belgium were the OECD countries with the largest propensity to collaborate internationally (Figure 1). (OECD, 2017[2])

Figure 1. International scientific collaboration, 2005 and 2015

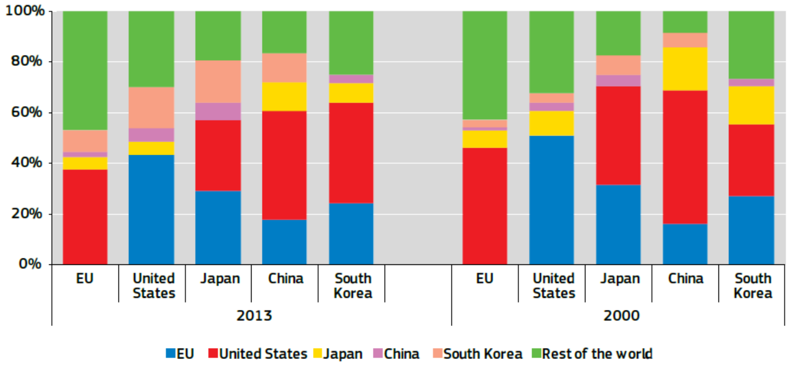


Source: OECD Science, Technology and Industry Scoreboard 2017

45. The United States remains the main partner in science collaboration for the European Union while China is becoming increasingly important as a strategic partner. While Japan collaborates equally with the EU and the United States, South Korea and China tend to

collaborate more with the United States than with the EU. This seems to suggest that the United States have been able to take better advantage of the emerging research capacities of these economies than the European Union (Figure 2). (European Commission, 2016[4])

Figure 2. Main partners in international co-publications, 2000 and 2013



Note: Elements of estimation were involved in the compilation of the data.
Source: Science, Research and Innovation performance of the EU 2016

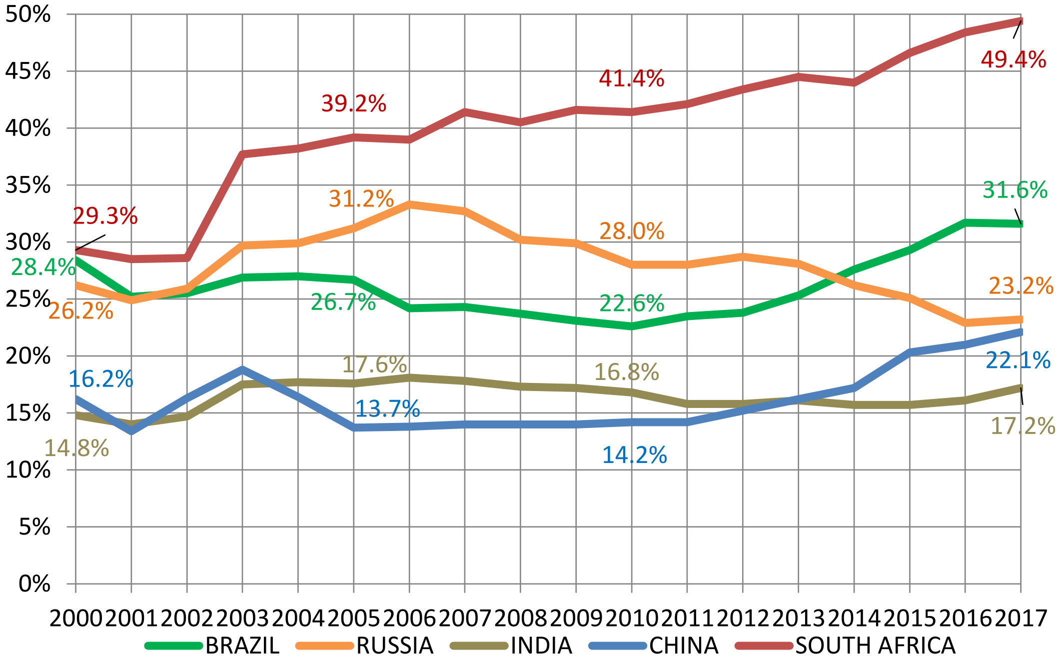
46. Within the EU, the United Kingdom, France and Germany collaborate the most. Switzerland also has strong collaboration with Germany and France and the United Kingdom. Quite extensive work has been done by Caroline Wagner and Loet Leydesdorff on studying patterns of international collaboration in science, based on co-publication data (Wagner and Leydesdorff, 2005[3]), (Loet Leydesdorff, 2008[5]). They show that one possible explanation of the dynamics of international collaboration in science is preferential attachment, which means that a certain number of well-connected institutions are able to attract new collaborators seeking reputable partners. They also show that a core group of collaborative countries tends to dominate.

1. *Co-publication activities of BRICS countries*

47. Regarding the co-publication activity in BRICS countries, since 2000, the BRICS countries have demonstrated a significant increase in the number of publications in Scopus and increased their share in the global volume of publications. In 2010, the total number of publications of BRICS countries exceeded the number of publications in the United States, and in 2014, BRICS countries almost closed the gap with EU-28 countries.

48. In total, in 2015, the BRICS countries accounted for almost 29% of the global volume of publications in Scopus, of them China—18%, India—5%, Russia and Brazil—2.6%, South Africa—0.72%). Largely this was achieved through the exceptionally high rate of growth of publication activity in China (Figure 3). (Shashnov S, 2018[6])

Figure 3. Share of internationally collaborated publications in total number of publications of BRICS countries in Scopus



Source: Shashnov S, 2018

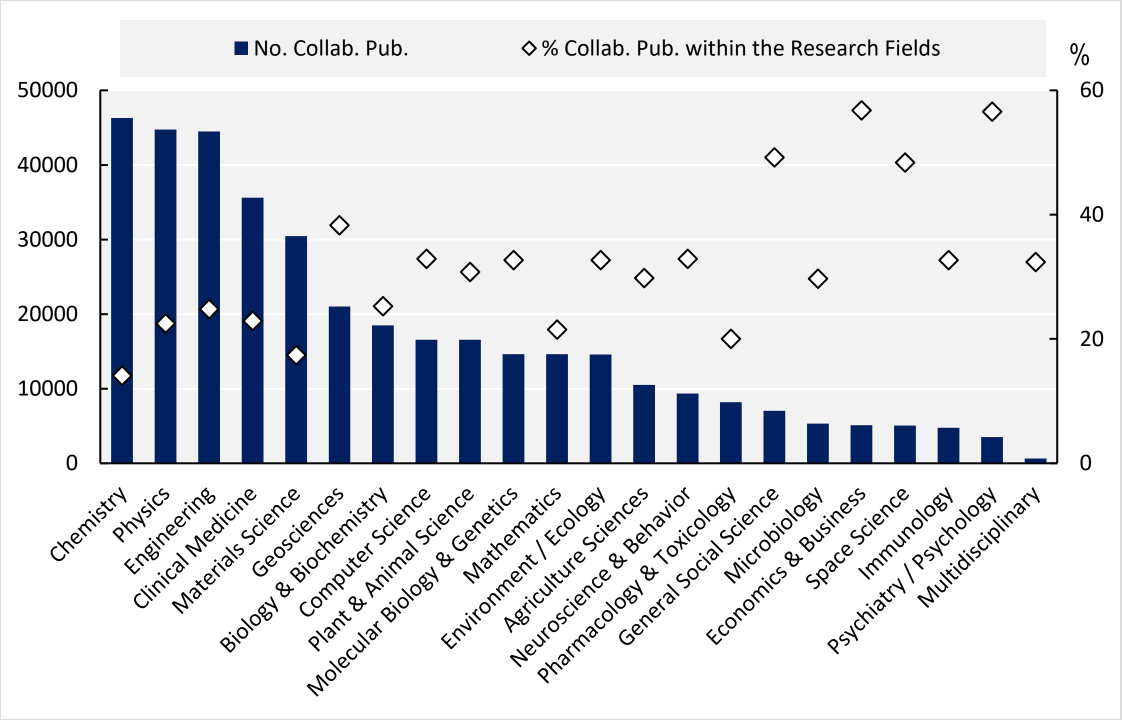
2.

3.

Box 1. China's International Scientific Research Collaboration

As shown in the Figure 1 of Box 1, in the past 10 years, Chemistry, Physics, Engineering, Clinical Medicine, and Materials Science are the largest areas in terms of volume of publications and al. pub. More than half of the international publications in the 22 ESI fields were from these five research Fields. Among the research fields with more than 10,000 collaborative publications, the percentage of international publications within Geosciences was the highest (38.3%). (NCSTE and Clarivate Analytics, 2017[7])

Box 1 Figure 1. China's Collaborative Publications by Research Fields during 2006-2015

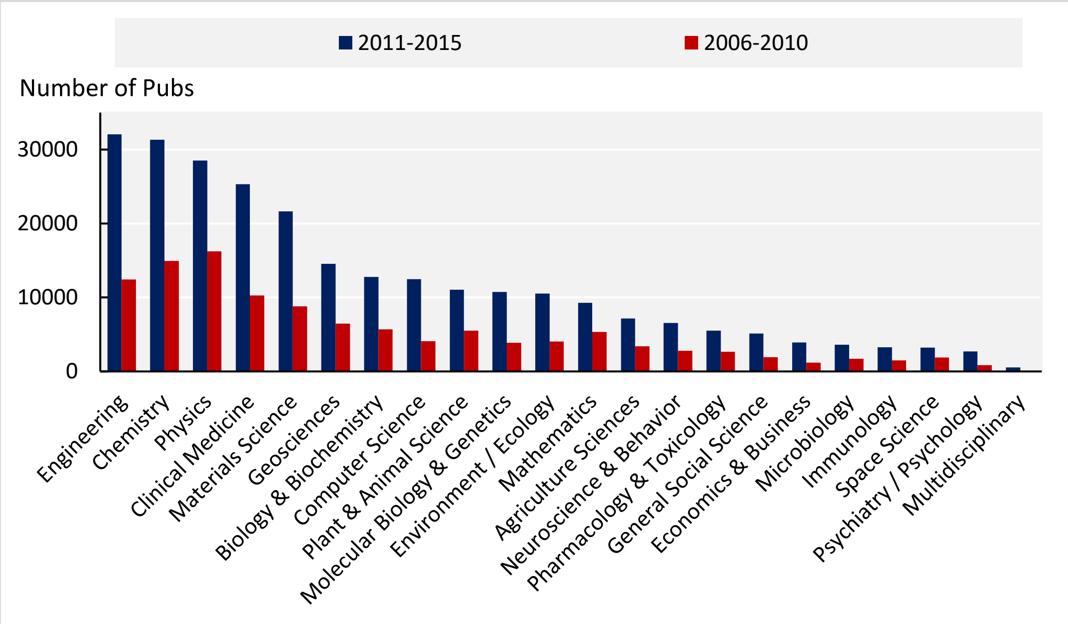


Source: NCSTE and Clarivate Analytics, 2017

Box 2. China's International Scientific Research Collaboration

As shown in Box 2. Figure 1, Physics is the largest discipline in terms co-publications during the 2006-2010. During the 2011-2015, co-publishing in engineering and chemistry exceeded that of physics and became the top two research fields with the most collaborative publications. Among the top 10 Research Fields in terms of the scale of international collaboration, the growth in computer science was the greatest. The number of collaborative publications in chemistry increased from about 15,000 during the 2006-2010 to around 31,000 during the 2011-2015, with a growth rate of over 100%. (NCSTE and Clarivate Analytics, 2017[7])

Box 2 Figure 1. Growth of China's Collaborative Publications by Research Fields during 2006-2010 and 2011-2015



Source: NCSTE and Clarivate Analytics, 2017

49. There are also multiple motivations for the different actors and communities involved. Research scientists have their own rationales for international co-operation that may not operate in the same manner or tradition in the natural or the social sciences. At the institutional level, higher education institutions and public research labs such as the Fraunhofer institutes have also adopted internationalisation strategies to tap into new knowledge networks and to attract and exchange talent.

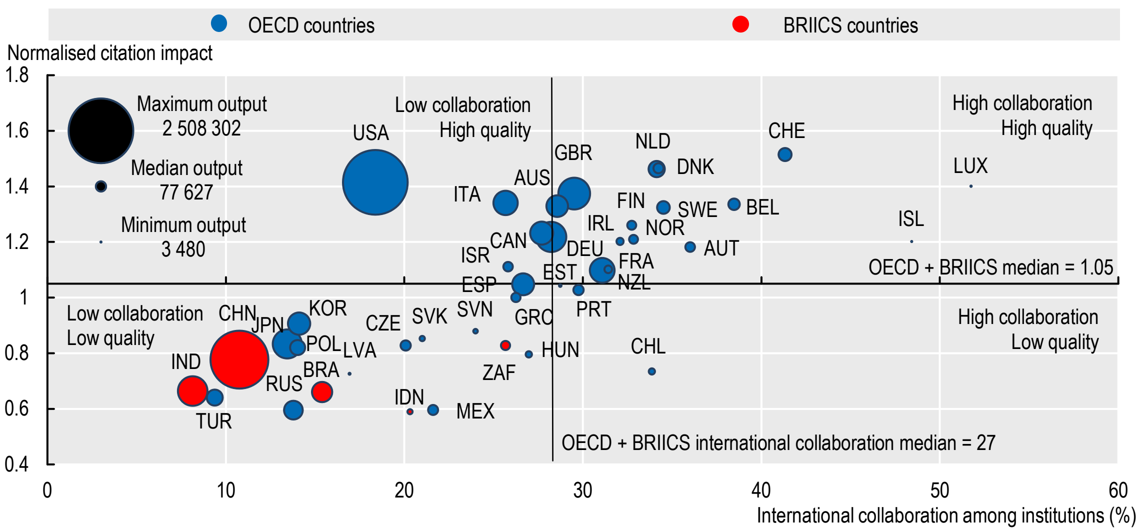
50. Also, some research fields are more prone to international co-operation than others and this is supported by co-publication data. Indeed, some scholars have postulated that subject-specific cultures affect collaboration patterns and spatial dependencies (Henneman and al., 2012[8]).

51. Another feature of scientific research that may influence the propensity to internationalise is that some research fields have a more direct impact (for a variety of reasons that are outside the scope of this paper) on technological development and in turn on productivity and economic growth. Again, economic competitiveness goals remain one of the priorities for funding public research and does not always favour international co-operation.

52. Evidence shows that stronger international collaborations clearly have a positive impact on the overall performance of national *research* systems, however. Measures of scientific research collaboration and citation impact (a quality measure of scientific publishing) at the country level are positively correlated, especially for economies with lower levels of scientific production. These smaller economies attempt to overcome their limited scale by participating more intensively in global networks. (Figure 4) (OECD, 2017[9])

Figure 4. The citation impact of scientific production and the extent of international collaboration, 2012-16

As an index and percentage of all citable documents, based on fractional counts



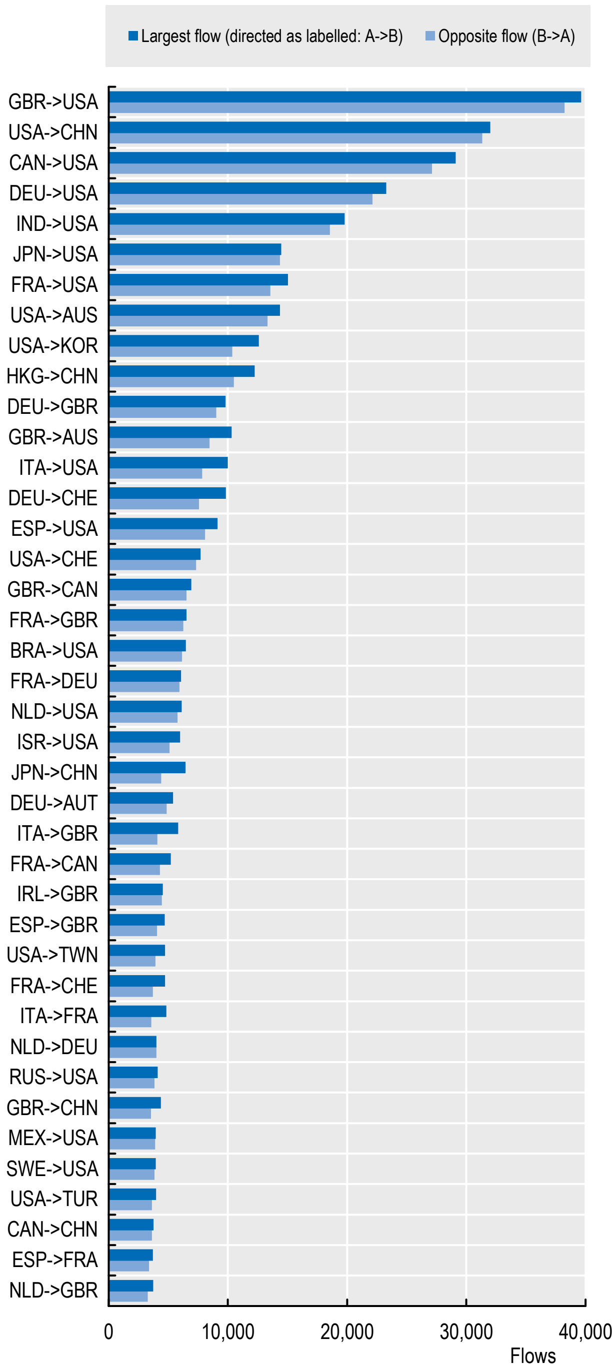
Source: OECD Science, Technology and Industry Scoreboard 2017

1.4. International mobility trends

53. Another measure of international co-operation is international mobility of researchers. Scientist mobility facilitates the circulation of scientific knowledge. One way to track the mobility of scientists is to trace changes in institutional affiliation over their list of publications in scholarly journals. This approach shows that brain circulation (churn) is far more important than brain gain/drain (net flows). The nine largest international bilateral flows of scientists over the period 2006-2016 involved exchanges with the United States. Of the top 40 connections, this country was a net beneficiary in 14 cases, followed by the United Kingdom with 6 and China with 5 (Figure 5). (OECD, 2017[9]). It is a fact of the matter that most researchers are concentrated in the OECD countries and the BRICs. International mobility therefore is concentrated among those countries that have capacity in R&D. This has important implications for co-operation with less developed countries.

Figure 5. International bilateral flows of scientific authors, 2006-16

Largest bilateral flows, by first and last recorded main affiliation



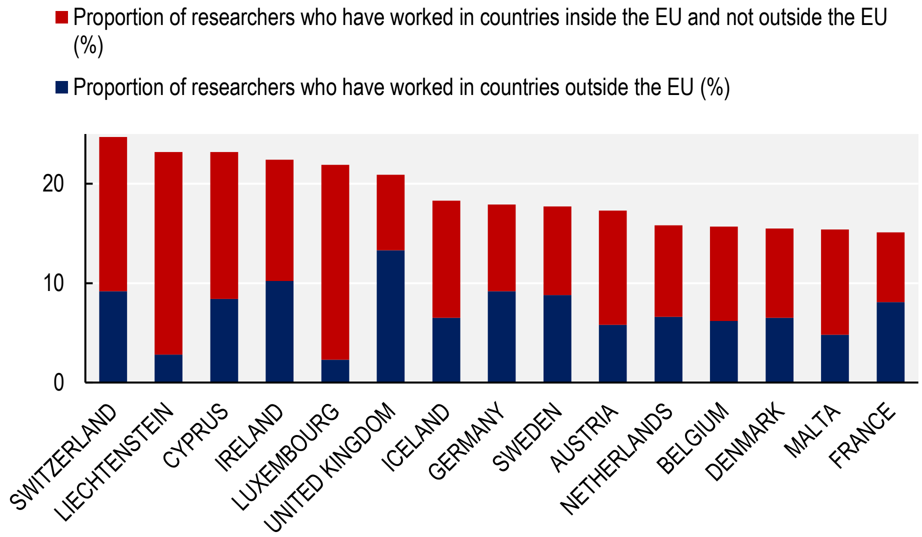
Source: OECD Science, Technology and Industry Scoreboard 2017

54. Data on bilateral flows from the UK show that the share of UK-affiliated researchers (including non-UK nationals) having worked abroad for more than two years in other EU

countries was 7.6% that is similar to the proportion of researchers in both Germany and France that had done so, at 8.7% and 7.0%, respectively.

55. The proportion of UK-affiliated researchers who worked in a country outside the EU for more than two years over the same period was 13.3%, whereas the proportion of researchers from Germany and France who had done so were lower, at 9.2% and 8.1% respectively (Figure 6). (Royal Society, 2016[10])

Figure 6. European countries ranked by the proportion of their research population that has spent more than two years working in a different country between 1996 and 20117



Note: This data includes active researchers who have migrated to another country (or countries) for at least 2 years. Although some researchers may have spent more than two years in both an EU and a non-EU country, such researchers are only counted as having worked outside the EU, due to the way in which this data was produced.

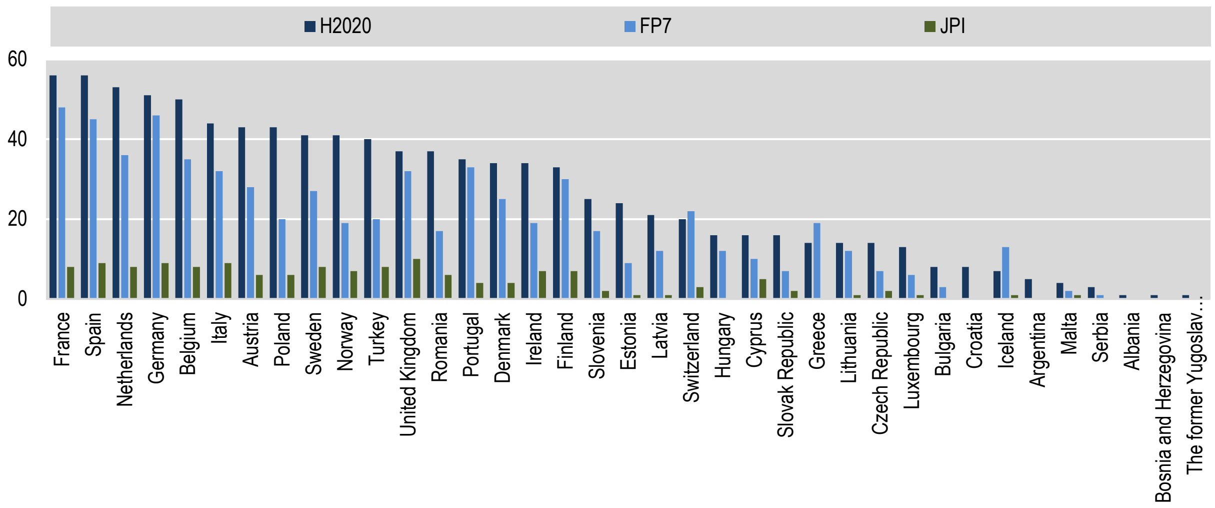
Source: Royal Society, 2017. UK research and the European Union: the role of the EU in international research collaboration and researcher mobility

1.5. Funding for international co-operation

56. Research funding that is allocated to international research activities is another measure of the increase in international co-operation in science and technology. R&D statistics collected by the OECD and Eurostat based on R&D performers' reports show that funds provided by the European Commission (EC) are an important source of international funds for R&D performed by higher education institutions and government research organisations, the largest sums of which flow to Germany and the United Kingdom. These funds play a more important role in the United Kingdom, underpinning 7.4% of higher education and government R&D, compared to 3.9% in Germany – a share larger than that of any other Western European country, apart from Greece or Ireland.((OECD, 2017[9])

57. France, Spain, Netherlands, Germany and Belgium have a large share of participation (more than 50%) in Horizon2020 (2014-2020). Participation in programmes by Poland, Norway, Turkey, the United Kingdom, Romania, Ireland, Estonia, Latvia, Slovak Republic, Luxembourg or Bulgaria have doubled compared with that of The Seventh Framework Programme (2007-2013). (Figure 7)

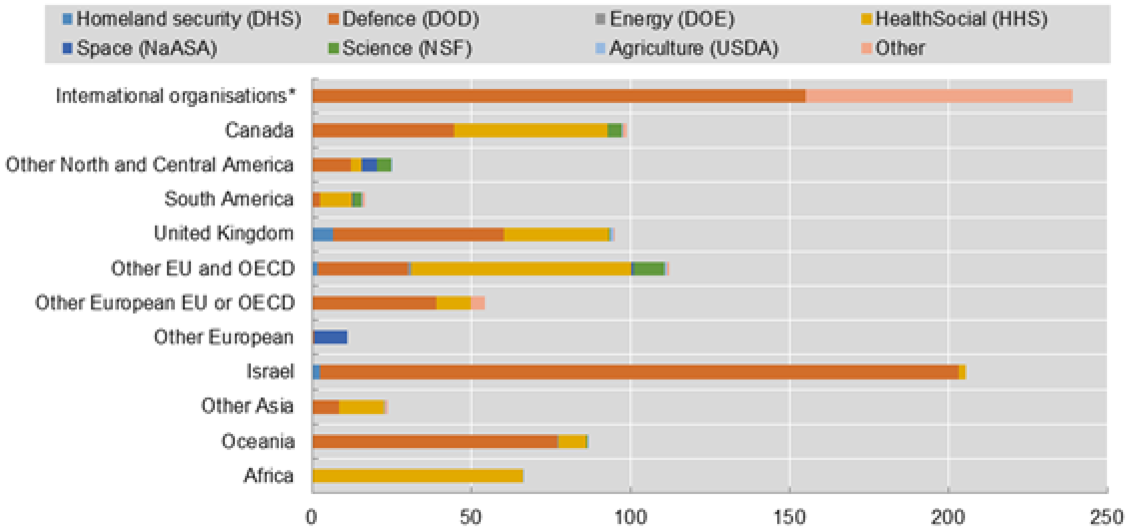
Figure 7. Europe-wide transnational public R&D programmes, 2018



Source: Europe-wide transnational public R&D programmes (2018)

58. Another illustration of international R&D funding can be found in US-data about the Federal Government funding of R&D performed by foreign organisations. The data shows that the US Department of Defense provides the largest share of funds. The allocation of funds by region/country and purpose (as implied by the identity of the funding US Federal body) reveals a combination of interests, affinities and perceived strengths in the countries receiving the funds. Israel, Canada and the United Kingdom are the largest foreign recipients of R&D funds from the US Federal Government. Funding for health and social related research is the most evenly distributed geographically. Funding to Russia (under other European) is principally related to space-related research (Figure 8).

Figure 8. Federal obligations for R&D to foreign performers, by economy and agency, 2015



Note: International organisations displayed including funding to Belgium reported as under DOD (NATO)
Source: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FYs 2015–17. Accessed from https://ncsesdata.nsf.gov/fedfunds/2015/html/FFS2015_DST_098.html

1.6. STI funding for co-operation on the grand challenges: Insights from the Uber Research Dimensions Database

59. Official data on the amount of public research funded to support international STI co-operation for the grand challenges is inexistent at international level and often even at national level. Using data from a private source called the Uber Research Dimensions for Funders Database offers another perspective on amount of research funding being directed towards international co-operation for the grand challenges. The database covers funding councils in 35 countries and thus caution should be exerted in reaching broad conclusions from what is clearly not a fully representative dataset. In the absence of standard tags, the Secretariat used the following key words to identify the number and characteristics of R&D projects funded in the countries included in the database:

i. international collaboration;

ii. basic research vs. applied research vs. innovation

iii. relevance to the Sustainable Development Goals.

60. Therefore, a keyword combination was used as a proxy. Nevertheless the findings are interesting and do raise some questions about how much international co-operation in STI is really going on, specifically with regard to the grand challenges.

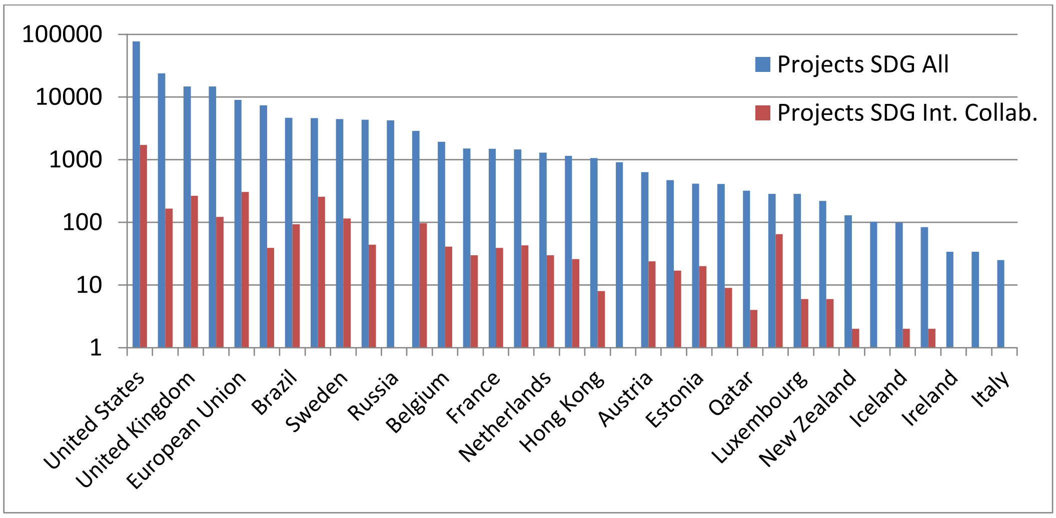
61. Research projects with a stated international component[5] represent a very low fraction of all projects. Using the above keyword combination, the share represents of 0.9% of the

[5] It should be noted that due to the key word search "international", funding for international projects for EU Horizon 2020 or other EU programes may not have been counted if they did not include the word international in their descriptions. In the EU context, international co-operation is often assimilated to co-operation with countries outside the EU ("third countries"). See Annex 1.

total, and while this may vary depending on the keywords chosen, it does not exceed 7% with even the broadest definition. Smaller countries (such as Estonia, Norway and Croatia) have a higher propensity to fund international co-operation rather than large economies. This can be interpreted as a quest for critical mass of competences abroad.

62. Research projects mentioning applications or applied research represent about 17% among all projects, and projects mentioning innovation represent less than 5%. Both applied research projects and innovation projects are more likely to be involved in international collaboration, and their average size is bigger than that of average projects. It should be stated that greater co-operation in applied research does not imply a need for reduced attention to basic research. Indeed, there are good reasons for continuing support for such research, notably the relatively larger knowledge spillovers generated by basic research compared to applied research.

Figure 9. Number of funded research projects related to the SDGs and share involving international research co-operation



Source: OECD extractions based on the Uber Dimensions Database.

63. Projects which can be related to one of the 17 Sustainable Development Goals represent about 11% of the total number of projects in the sample (Figure 9), but the number of projects varies, with SDG 3: Good Health and Well-Being is most frequently represented, with about 2.1% of the total, while SDG 5: Gender Equality is the least represented with 0.22%. Average size of projects also varies, with projects related to SDG 3: Good Health and Well-being having the largest size, and those for SDG 17: Partnerships for the Goals having the smallest average size.

64. International collaboration is more than twice as likely for SDG-related projects (2% vs. 0.9%), and varies from 0.8% for SDG 3: Health and Well-being, to more than 5% for SDG 17: Partnerships for the Goals.

65. Analysing the SDG projects per scientific discipline, we find a very high representation of studies of human society, engineering, economic sciences, agricultural and veterinary sciences. On the other end of the spectrum, there is very little contribution from mathematical and physical sciences, as well as history and archaeology, perhaps because many of these disciplines are also funded by national academies and institutional funds.

66. The main funding agencies by overall number of projects are the European Commission (leading by total value of projects) and the National Science Foundation (leading by number of projects). However, additional analysis by percentage of projects dedicated to SDG's shows that some smaller agencies also give high priority to SDG-related research topics.

Section Summary

67. The data on co-publication and international funding of research illustrate the increase in internationalisation of public research activities. The data show there are different patterns globally. Co-publication within OECD countries continues to increase. Within the EU, the United Kingdom, France, and Germany dominate collaboration. BRICS countries increased their publication output and international collaboration. China in particular has become a major partner for countries to collaborate with especially in fields such as geosciences, physics and engineering. In other areas where the number of Chinese publications is low, co-operation is nevertheless high such as in space science, and immunology. Within the EU, collaboration is Eastern European countries is growing. The United Kingdom has strong collaboration with EU but also with the United States. Mobility of researchers has also increased globally by various measures. However, data based on author flow shows clear patterns in the direction of bilateral flows between countries, suggesting that researchers respond to specific push and pull factors such as institutional prestige, disciplinary or scientific leadership relative to home country as well as funding opportunities and visa arrangements.

68. One of the implications from the co-publishing and mobility data is that countries need to develop national research capacity in order to co-operate and attract talent flows. Institutions and governments can help initiate and support such collaborations as in the case of the MIT-Portugal university partnerships. Research funding for collaboration and mobility will also affect the direction of co-operation.

69. Data on funding of international collaboration in STI is limited to EU funding and to data from US Departments and research funding agencies. Similarly, official data on international co-operation for the grand challenges is inexistent. Based on data from the Uber Dimensions Funders Database in 2017, funded research projects that could relate to one of the 17 Sustainable Development Goals represent only about 11% of the total number of projects, and international co-operation occurs in about 2% of these, i.e. international co-operation for SDG's represents about 0.2% of all funded projects in the database.

The challenge of “grand challenges” for STI policy and international co-operation

1.7. Definitions

70. As previously stated, international co-operation in science and technology for the grand challenges, as a field of study, has been explored less systematically than the internationalisation of public or private research. The reason for this has partly to do with the relatively recent emergence of “grand challenges” as a framing concept for STI policies and international co-operation in particular even if variants of the term have been used for decades in research policy in a narrow sense (Box 3).

71. Grand challenges such as climate change, population growth and aging, are a challenge for STI policy making because the problems are simultaneously global and local; complex and systemic such that solutions are not only technological but also social. This poses new challenges and rationales for policy action (Mowery et al., 2010[11]), (Kuhlmann and Rip, 2016[12]) (Lindner et al., 2016[13]).

72. The grand challenges are also heterogeneous; some challenges represent public good problems on a global scale. Others present public good problems on a national or bilateral/regional scale (e.g. ocean or air pollution in cross-border regions). The challenge for countries is how to balance their national priorities and goals (e.g. competitiveness goals, research excellence goals) and the need for co-ordinated and concerted action at international level to solve "global public good" problems as distinct from public goods problems that can be addressed at national level (e.g. provision of public health services or compulsory education).

Box 3. Defining the “grand challenges”

There is no standard definition of what constitutes the "grand challenges" facing humanity, neither at a global scale nor on a national level. In many ways, defining grand challenges is an exercise in semantics and perspective. Dr. David Hilbert, a German mathematician is credited for first coining the term in 1900 when he identified 23 challenges in mathematics (Nature, 2015). In the 1980s, it was used by Kenneth G. Wilson, a physics Nobel laureate who advocated funding for scientific challenges in high performance computing in response to research competition from Japan. By the 1990s the US Office of Science and Technology Policy (OSTP) used the term in relation to several research and technological challenges [6]rather than societal challenges (OECD, 2016b, Hicks, 2014). At a 1997 OECD conference on international co-operation in Seoul, Korea the Japanese representative framed the issue of grand challenges as "Society-Oriented R&D". When, in 2003, the Gates Foundation and other partners, notably the US National Institutes of Health (NIH) launched the "Grand Challenges in Global Health Initiative" to address the health needs of developing countries it caused a tremor of sorts in research councils throughout the world. The Gates initiative

[6]Technology challenges can also be defined in relation to the risks brought about by scientific and technological progress itself such gene editing technologies and artificial intelligence, just to name a few. Addressing these technological challenges and related risks arguably requires policy frameworks for international collaborations of a different type that are outside the scope of this report (e.g. involving trans-border regulatory bodies, ethics commissions, and public acceptance of technology).

drew attention to the gaps between the health research priorities of developed countries and the wider needs of humanity. For the EU, the question of climate change and the challenge for RTD policy was entry point in 1998 for embracing the "grand challenges". This was followed by the 2008 Green Paper for the European Research Area (ERA) and the Lund Declaration in 2009 under the Swedish EU presidency.

In the EU, the "societal challenges" which are the approximate equivalent of the grand challenges, are set by the European Commission, in consultation with its member states, and implemented through work programmes with input from multiple stakeholders. For this purpose 19 Horizon 2020 Advisory Groups were set up as consultative bodies representing the broad constituency of stakeholders ranging from industry and research to representatives of civil society to inform the implementation of biannual work programmes.

Climate change and the related challenge of global energy supply are the clearest examples of grand challenges but so are access to clean drinking water, global health and international food security. These challenges all figure prominently on the agendas of the OECD, the EU and the G20 and, most notably the UN with the development of the Sustainable Development Goals. To a large extent, the 17 Sustainable Development Goals provide a powerful framework for thinking about the grand challenges. The SDGs represent "globally perceived priorities" that have been agreed upon by the global community. As such they represent "legitimate" priorities for societies and governments. The grand challenges represented by the SDGs or the Horizon 2020 Societal Challenges represent not just priorities but focal points for urgent action. A recent survey of OECD countries found that the majority of respondents considered the definition of grand challenges as grounded in a national perspective, but that international definitions provide reference points for science, technology and innovation policy (OECD, 2017).

73. At national level, this implies a change in the formulation of national policies in science and technology as well as in the instruments and the distribution of roles between different actors, including non-state actors. But as pointed by (Kuhlmann and Rip, 2016[12]), (Foray and Mowery, 2012[14]) in the area of STI, the response is often reduced to one of calling for more "excellent research".

74. The impossibility of addressing global challenges in their entirety (Edquist 2012[15]) has led governments to break down the grand challenges into smaller pieces and develop "challenge-driven" oriented research and innovation policies. The “challenge oriented” approach has some similarities with the traditional “mission oriented innovation policies (Ergas, 1987[16]); (Gassler, Polt and Rammer, 2007[17]).”, namely as regards the concentration of funding and resources in specific areas/sectors of activity.

1.8. Links between mission innovation and grand challenges

75. Calls for "new mission" oriented approaches that equate tackling the challenge of, for example, renewable energy with an "Apollo" type mission led research programme have largely been dismissed due to the complexity of the challenge and the need to co-ordinate policies and actors across a range of areas including outside the research field such as consumers and their adoption of new technologies and behaviours (Mowery et al., 2010[11]), (Smith, 2017[18]) (OECD, 2010[19]).

76. Mission oriented approaches may still be useful in some areas (e.g. when the technological path is known) but in the face of uncertainty, centralised decision-making and command and control modes of governance can actually suppress innovation. There is therefore a potential trade-off between the efficiency and directionality compared to a more dispersed and less structured organisation of research and innovation efforts.

77. At the EU level, there has been an effort since 2010 to foster challenge driven approaches to STI policies through collaborative initiatives such as the Joint Programming Initiatives (JPIs) which aim to "pool national research efforts" among EU members and the European Innovation Partnerships (EIPs) that foster co-operation between public and private actors at local, regional or national level to tackle the grand challenges.

78. The need for directionality that is supportive rather than prescriptive and deterministic has led to calls for redefining the role of the state towards one that defines broad growth directions instead of specific missions; and shapes new market landscapes instead of addressing market failures ((Kuhlmann and Rip, 2014[20]); (Mazzucato, 2015[21]). This is echoed by the new directionality in national innovation policies such as the Top Sector approach in the Netherlands or the Sweden's Strategic Innovation Programmes (SIPs). The latter are thematically focused around a societal challenge involving multiple actors and ex ante extensive consultation but with a strategic focus and key targets (e.g. zero net CO2 emissions in the case of Sweden's SIP focused on Smart Sustainable Cities).

79. However, grand challenges are transformative in the sense that they are part of overall societal development rather than just arguments for setting priorities for "directionality" in research and innovation systems ((Edler and Boone, 2018[22]). Furthermore, the new directionality for challenge-driven policies also has to integrate demand-side policies in the policy mix for innovation, such as public procurement, regulation, standards, creation of markets, user-led innovation initiatives (Borrás and Edquist, 2013[23]); (Edler and Georghiou, 2007[24]).

80. Directionality does not mean that curiosity-driven research should be abandoned in favour of challenge-led approaches. Indeed, there is a reassessment of the contribution of basic research to meet grand challenges and desire to provide an enabling environment for both experimentation and implementation (Edler and Fagerberg, 2017[25]). Some observers have argued for example that advances in medicine or in basic sciences can and should be advocated regardless of their direct or indirect impact on economic growth, since they generally foster the development of humanity.

81. While government have long supported "mission oriented" research in the areas of health, agriculture, defence and other public missions of government, the focus of these efforts has been on problems that affects the citizens of a country, their needs as well as the needs of national industry. This is justifiable as most public research in academia and mission oriented government labs are funded by public money. Although, as pointed out by Mowery and Nelson, mission R&D and societal challenges are related; many missions can inform current decisions and collaboration on grand challenges ranging from agriculture to energy (Foray, Mowery and Nelson, 2012; OECD, 2016).

82. The key difference between mission oriented research agendas and grand challenge agendas are a) global nature requiring cross-border collaboration; b) there global public good or semi-public good dimension; and c) their open-ended nature requiring long-term horizon and flexibility in agendas (Kuhlmann and Rip, 2014; OECD, 2012).

1.9. Main barriers and governance issues in STI collaboration for the grand challenges

83. The literature on international co-operation for the grand challenges has identified several factors holding back international co-operation (OECD, 2017), as follows:

- national research focus;

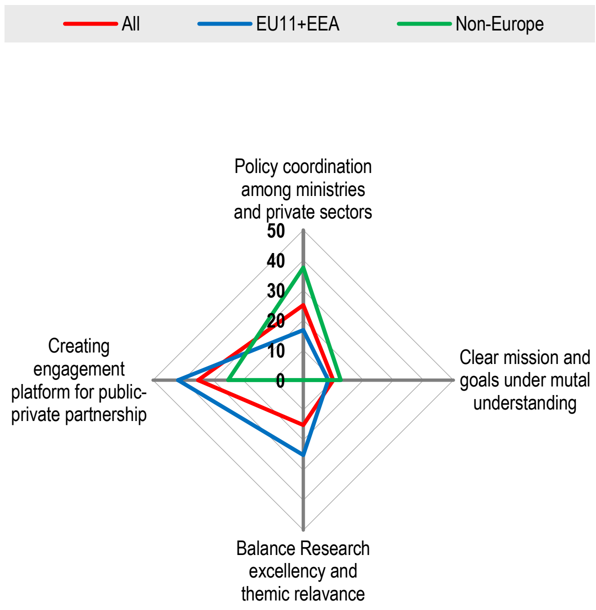
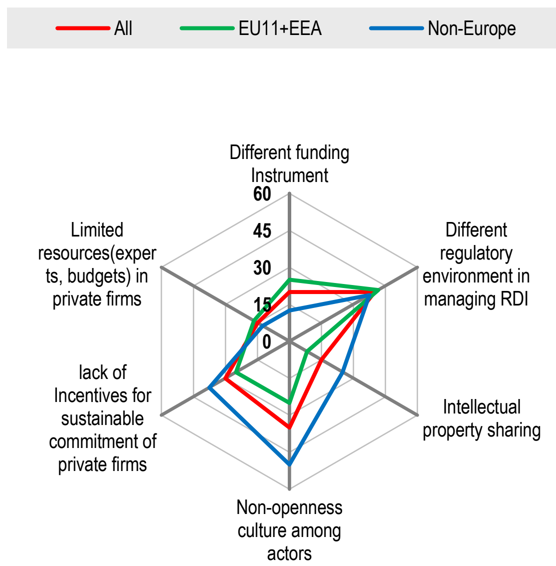
- global public-good problems, with individual countries unwilling to pay the costs of action (“tragedy of the commons”);
- lack of knowledge of partners’capabilities, especially in developing countries;
- lack of trust and legal regimes;
- weak intellectual property rights (IPR) protection, especially in less-developed economies;
- low government and business capacity in partner countries, including insufficient skills and lack of necessary research infrastructure to enable international co-operation ;
- national STI governance frameworks that hinder international co-operation if they are not well aligned;
- fragmented bottom-up and non-state initiatives (e.g. universities, nongovernmental organisations, foundations).

84. The CSTP mapping survey (OECD, 2017) identified additional obstacles to international STI co-operation such as challenge of developing governance model that would associate the regional or local governments in strategy, planning and operation. There is also a lack of dedicated funding for large-scale and long-term co-operation. Fragmentation of funding agencies – and of the rules and procedures for research funding – is also an important obstacle.

85. The survey respondents noted the difficulty in getting sustainable commitment from business firms; the lack of a culture of openness and IPR barriers to partnering. Differences in the regulatory environment; challenges of creating platforms for public-private partnerships and balancing research excellence with thematic relevance were key challenges in collaborating.

86. Removing barriers to the design of public-private partnerships - from the conditions and rules on funding and expenditure as well as research quality assessment criteria and data and IP sharing rules with company partners - are potentially important in order to achieve greater impact from international STI co-operation.

Figure 12. Main barriers to international STI partnerships for the grand challenges

Main barriers to governance	Main barriers in developing partnership
	

Source: OECD based on response to the 2017 CSTP Mapping Survey.

87. As regards, the governance models used to implement collaborative projects, most countries follow traditional governance models whereby government bodies govern and oversee operations through committees (or separate authorities) established along functional areas (finance, human resources, programmes).

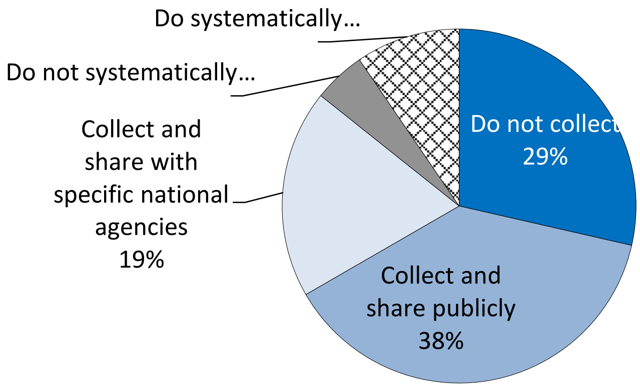
Stakeholder participation

88. Another element that characterises international STI co-operation for the grand challenges is the involvement of actors outside the research and government communities in setting priorities and implementing co-operation. Charities, foundations, business and NGOs increasingly play a role defining and shaping government agendas for international STI co-operation on the grand challenges through several channels. On the one hand, non-government actors play an advisory role on thematic issues and on the other, they may also be involved in priority and research aged setting process through formal and less formal means. Several countries as Australia, France, Germany and the Netherlands have formal and active policies to engage a broad range of non-state actors in agenda setting for international collaboration while other countries such as Japan and Russia focus on the main research actors and business. Digital technologies, platforms and research crowdfunding have also widened the participation of citizens in engaging with research, including research collaboration at the international level.

Sharing research data and information

89. Sharing information and data on research agendas for the grand challenges helps to reduce overlap and duplication in funding. It can also help identify future partners and increase opportunities for collaboration in general. At international level, there have been recent global initiatives to collect such data around specific fields such as in health R&D such as the G7 initiative on tracking R&D funding in the area of neglected diseases (Box 4). The WHO R&D Observatory, which compiles data on health R&D funding project involving developed and developing countries, is another case in point.

Figure 13. Share of respondents whose ministries/funding agencies systematically collect and share data on international STI co-operation for grand challenges



Source: OECD, Responses to the CSTP Mapping Survey

90. Nearly three quarters of the respondents noted that public funding agencies collect data on international co-operation in STI (Figure 13). In addition, although much data is systematically collected, much of it is used internally or shared among agencies and other stakeholders involved rather than the general public. Much of the data that is shared concerns R&D spending data (e.g. in Australia and Norway) while detailed data on programme and project descriptions are available through special requests.

91. The case of the Research Council Norway is illustrative. The RCN collects information on international collaboration in funded projects, including collaborating countries and names of foreign institutions with formal collaboration agreements. Funded projects are also classified by various thematic categories by the RCN. The data on collaborating countries are not published in the public electronic portal for statistics on R&D grants, but are available on demand.

Box.4.Recommendations to the G7-science ministers with regard to better mapping of global health R&D on Neglected Tropical Diseases and Poverty Related Diseases (NTD-PRD) as a basis for informed policy-making and co-ordinated research

Currently, it remains a challenge to keep up with the latest data on R&D activities and funding. The G7 Science Ministers have recognised the need and benefits of sharing information and data on national R&D activities and public financing of such R&D activities. Analysis of data should enable the G7 to identify R&D gaps and needs, capacities and expertise, and in turn facilitate informed policy-making. Current limitations include insufficient data availability and insufficient ability to compare across platforms and datasets. Additionally, data collection and analysis mapping of R&D activities and financing may be driven by different objectives (e.g., for informed policy-making and priority setting, for co-ordinated research activities, for exploiting synergies and creating critical mass). To enable better mapping of global health R&D on PRDs/NTDs the G7 members should:

- make information and data on their relevant national R&D activities and public R&D financing publicly available and accessible;
- where required, further develop and improve their national information systems in terms of coverage, completeness, consistency, and ease of use, with the goal to report the significant majority of their national, publicly funded R&D activities on PRDs/NTDs to the *GFinder* and the *WorldRePORT* by 2018;

Source: G7 Working Group (2017) Report on Neglected Tropical Diseases and Poverty Related Diseases (NTD-PRD). Available at: *http://www8.cao.go.jp/cstp/english/others/20160517communique_1.pdf*

Evaluation of international research co-operation for the grand challenges

92. Research funding councils and Ministries are the main actors involved in the evaluation and monitoring of internationally collaborative research for the grand challenges used in the CSTP mapping survey (climate and environment, health and societal goals). In the case of climate and societal challenges, external evaluation agencies were used more frequently than in the case of international collaboration on health challenges.

93. Regarding the main indicators used to evaluate the impact of international STI collaboration projects for the grand challenges by thematic areas, the CSTP survey showed that the majority of respondents highlighted indicators related to research excellence followed by human capital development and indicators of socio-economic impact and innovation. Differences in the types of indicators used to evaluate projects by field or type of grand challenge were marginal. In most countries, the types of indicators used to evaluate international research collaboration vary as processes are determined by the agency or organisation managing collaborative project funding. Germany's Federal research ministry (BMBF) has established a set of indicators to reflect the degree of internationalisation of STI activities and aims to integrate research on grand challenges in the framework.

94. Lessons from the GSF work on international co-operation in the area of climate show that there is no one "blueprint" for evaluation and impact assessment, and metrics will depend upon the objectives of the specific programme or project. Therefore, it is important that special context of the particular project or programme are taken into account in the evaluation. Rigid ex-ante assessment frameworks often do not allow research goals to evolve as the work progresses (OECD, 2014[26]).

1.10. Summary discussion

95. National STI policies are increasingly challenge-driven and priorities are set according to societal challenges, even if there is no standard definition on how these are defined at a global or national level. There is a permanent tension between orienting STI policies (and funding) towards national goals such as competitiveness versus the grand challenges that fall outside national boundaries. In fact, many national research strategies in OECD countries and beyond try to align competitiveness goals with societal challenges under the banner of "opportunities". The German High Tech Strategy is a case in point. The Chinese government has designed its "Made in China 2025" to focus on enhancing innovation in ten key sectors including ICT, robotics, agriculture, aerospace, marine, railway equipment, clean energy, new materials, biological medicine and medical devices - all of which can be useful in addressing the grand challenges. In other words, tackling the grand challenges is a way to position a country's innovation system on the path of new growth areas. This is the "win-win" approach. However, the provision of a "global public good" such as biodiversity may not be achievable through collaborative win-win approaches. The national benefits/returns from collaboration on global public goods may not materialise in the same time frame or to the same extent to each country because global public goods transcend national boundaries. Furthermore, the national governance structures in many countries do not appear to favour a "challenge" approach. Such an approach requires strong vertical co-ordination, with significant horizontal alignment. This is especially challenging in countries where ministries have devolved the implementation of strategic research programmes to agencies. To succeed, new mission-oriented approaches will not only need to be linked to the grand challenges such as the SDGs, but will also require significant levels of funding, as well as specific co-ordination mechanisms involving companies and civil-society actors

96. A second implication from the discussion is that steering research and innovation towards the grand challenges cannot be solely the responsibility of the public research system. Public research systems are by and large oriented towards the societal needs and competitiveness goals at national level. National research funding agencies, through the use of competitive funding instruments for example, are keen to encourage competition among national research performers. This in turn focuses scientific collaboration on internal systems. Partnerships with companies and non-state actors including charities are a necessary condition for partnerships in STI as companies and NGOs for example are closer to the demand and user-side.

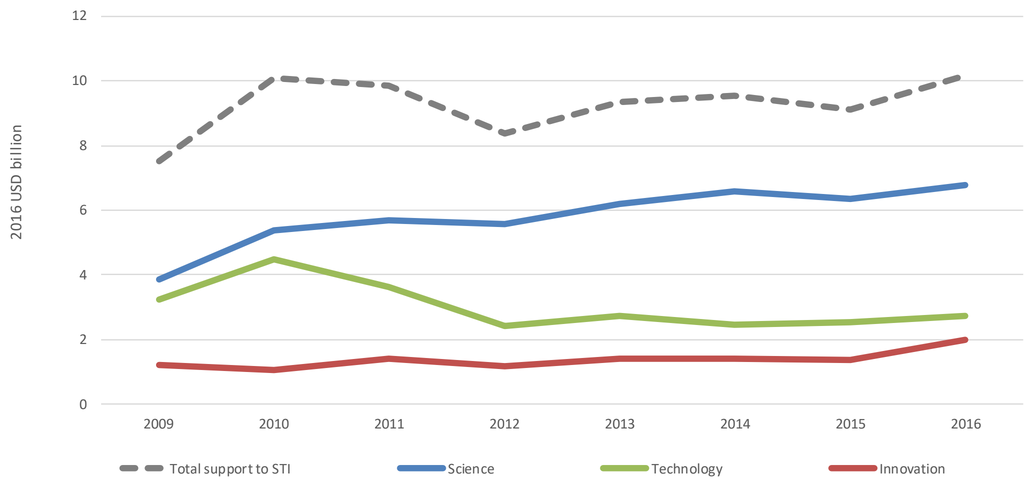
Lining STI policies and ODA

Introduction

97. The Daejeon Ministerial called for improving the data on international scientific collaboration that take place through development co-operation. Country specific data on R&D in Official Development Assistance (ODA) show this type of support is significant and has increased but gaps in the data limit the exploitation of potential synergies between international scientific research collaboration and developmental goals. Research data is patchy and codes for R&D are not available for all areas. Nevertheless figure 14 provides estimates of the amount of ODA concessional funding directed toward "STI activities" that reached some USD 10 billion in 2016. More than have of the funding went to activities related to scientific research as opposed to technology or innovation.

Figure 14. Estimated concessional ODA funding towards Science, Technology and Innovation (STI)

Disbursements in 2016 prices



Note: The sum of the three categories in this chart will exceed total support to STI because of activities contributing to several categories.
.*Source*: OECD (2018), OECD International Development Statistics database.

98. There is growing recognition in the Official Development Assistance (ODA) community that investment in research and innovation are essential to meet development goals. To some extent, capacity building in research has long been promoted by OECD Official Development Assistance agencies with a focus on poverty reduction, education, agriculture, and health for example. Over the past decades, the discourse in aid agencies has evolved to promote innovation, including social innovation so that institutional capacity can be created in countries to sustain research capacity over the long term and across more sectors of the economy.

99. Philanthropies and foundations are also active in the development space and a considerable share of their funding targets STI activities. Preliminary estimates carried out by the OECD's Development Co-operation Directorate on the importance of research activities in

philanthropy funding for development show that activities related to research or those channelled through universities, think tanks, research institutes etc. amounted to around USD 6 bn over 2013-2015 (25% of the three-year total).

100. It should be kept in mind that there are important differences in how the grand challenges are viewed from the perspective of developing countries versus developed countries. Some observers have pointed out that the meaning of "environmental" or climate priorities differs in the case of developing countries. Environmental problems like biodiversity are clearly a global issue but at the level of a developing country, that issue may come second to "local environmental challenges" issues like access to clean water and arable farmland.

1.11. Global efforts to promote STI in ODA

101. Several research councils in OECD countries are active in providing research funding for development such as Research Council of Norway, Swiss National Science Foundation (Programme for Research on Global Issues), and the Swedish Research Council (programmes to support development research).

102. In the UK aid funding includes a significant portion of research funding to support the operations of the aid agency or research to address development challenges. The Department for International Development (DFID) has a research budget of a similar size to the Global Challenge Research Fund (GBP 390 million per annum over the next four years). The UK's Newton Fund, established in 2014, uses science and innovation to promote economic development and social welfare in partner countries. It matches spending by partner countries in the developing world with UK ODA funds, with a UK investment of GBP 735 million to 2021.

103. Other examples of programmes and initiatives to support STI-related ODA include;

- *Canada*: In 2004, Canada set a long-term goal to invest 5% of its R&D budget to support to a knowledge-based approach to development assistance for less developed countries. There are two initiatives promoted by Global Affairs Canada for supporting research and innovation in developing countries; the International Research Development Center(IRDC) and the Grand Challenge Canada(GCC). While IRDC was established in 1970 and have supported over 1,900 research and innovation projects in developing countries to improve their lives, GCC launched in 2010 to support innovators in developing countries with bold ideas and big impact which integrate science and technology, social and business innovation.

- *Finland*: The Finnish innovation policies aim at encouraging companies for bold innovation, international growth and contribution to global challenges, which focus on circular economy, clean energy, digitalization and health. A key mechanism for integrating STI and ODA in Finland is long-term bilateral STI collaboration with partner countries. In addition, United Nations Technology Innovation Labs in Finland that was launched on December 2018 will be a new collaborative platform to provide problem-solutions for global challenges where multi stakeholders such as UN resources, private sector, academia and civil society work together.

- *France*: With the French president’s announcement of the plan to increase its ODA budget from 0.4% of GDP in 2017 to 0.55% by 2021, French ODA system is undergoing reforms such as supporting joint funds between the French Development

Agency(AFD) and the Caisse des Dépôts Group (CDG, main public financial institute). The reforms also aim to improve co-ordination among stakeholders and the promotion of innovation, including with the private sector. Twenty-nine percent of the total ODA budget in France is delivered through higher educations and public research institutes. Three public research institutes such as the Bureau de Recherches Géologiques et Minières*(BRGM*), the Agricultural Research and International Cooperation Organization(CIRAD) and French National Research Institute for Sustainable Development(IRD) are the main players dedicated to the sustainable development of tropical and Mediterranean regions with a scientific strategy targeted toward SDGs implementation and supported by ODA.

- *Japan*: For realizing 'society 5.0' which refer to a human-centered society by realizing the advanced fusion of cyberspace and physical space and by balancing economic advancement with the resolution of social problems, Japanese government is formulating the 'STI for SDGs Roadmap' through international collaboration. The Roadmap will specify concrete milestone to achieve 17 UN SDGs respectively with consideration of future disruptive technical development including Artificial Intelligence. In addition, Japan is promoting a research for development program of the Science and Technology Research Partnership for Sustainable Development (SATREPS) that is jointly financed by a research funder and an ODA funder in Japan. The SATREPS aims to address global issues and lead to research outcomes of practical benefit to both local and global society.

- *Korea:* In order to share Korea's past development experiences from the world's poorest to an industrialized countries with advanced technologies within a half century, Korean government is expanding the STI-based ODA programs which focus on helping developing countries improve their STI capability and support economic development and quality of people's life. For example, the program of the Science and Technology Innovation Center for Developing Countries support the cooperation of universities and research between Korea and developing countries to develop appropriate technologies that meet the needs of local residents and manufacturing infrastructures.

- *Netherlands*: With recognizing that government funding alone is not sufficient to achieve Sustainable Development Goals (SDGs), the Dutch government developed SDG Partnership that leverages the private sector for the contributions to the SDGs. The SDG Partnership is a consortium of up to six partners including NGOs, companies, public sectors and research institutes. The Dutch government covers only 50% of the costs in SDGP and the private partners should finance the other 50%.

- *Norway*: In terms of funding sources, the ODA funders in Norway have a low level of investment in the STI sector, but the Research Council of Norway(RCN) is mainly responsible for supporting research programs for development to achieve SDGs. For example, Vision 2030 is a funding mechanism that focus on innovation and scalable solutions in development with priority to innovation in health and education. RCN is also promoting the research programs for development on various UN SDGs such as climate action, global healthcare, life on land etc., with partners in developing countries such as India and China.

- *Sweden*: International Foundation for Science (IFS) was a Swedish research council established in 1972 of which budgets funded from a portfolio of donors and funders including development organisations and science academies. IFS supports young researchers in developing countries to have opportunities of carrying out research projects that can enhance our understanding of the realities of less developed societies and better address global sustainability.

- *United Kingdom*: The UK Government has committed to spending 0.7% as a proportion of the UK's Gross National Income (GNI) on ODA. While the Department for International Development (DFID) is mainly responsible for ODA strategies and policies in UK, the Department for Business, Energy and Industrial Policy (BEIS) is in charge of supporting the research and innovation program toward ODA based on the principles of the UK aid strategy. Total budget of research innovation on ODA in BEIS is approximately £4.3 billion from 2016-2020 which is mainly supported by the programs of International Climate Fund (ICF), the Global Challenges Research Fund (GCRF) and the Newton Fund. While the GCRF is a funding stream that supports cutting-edge research on global issues affecting developing countries such as famine, inequality, environmental degradation and global health challenges, the Newton fund builds research and innovation partnerships with 15 partner countries to support their scientific capacity development.

- *World Bank Group*. In addition to national governments, multilateral banks such as the World Bank Group also provide financing the projects for development aid that focus on strengthening national innovation system in developing countries. The organization supports developing countries in Africa to build their infrastructures for sustainable, technology-led economies and to boost the capacity of people and institutions to make the most of the social system in the face of emerging technologies. The World Bank attempt to harness disruptive technologies, data and expertise to solve development challenges and management risks; for example, the development bank launched an internal trust fund to encourage the use of disruptive technology in their project.

- *Wellcome Trust*. As one of the major global biomedical charities, the Wellcome Trust has invested over the 30 years in the research programs of which main aim is to strengthen research ecosystems that drive socioeconomic innovation, inspire outstanding researchers in Africa and Asia regions. Their research programs are also designed to address regional health challenges that millions of peoples face such as tropical diseases, respiratory diseases, malnutrition, reproductive health and HIV/AIDS. The philanthropy has also supported Wellcome Trust Centres for Global Health Research (WTCGHR) that build partnership between institutions in the UK and low- and middle-income countries for supporting capacity building in global health issues. The charity has also developed a campaign "Together Science Can" in partnership with science council, international science alliances and private philanthropies to promote international scientific collaboration through the removal of barriers to research mobility.

4. ***Main challenges and obstacles for strengthening policy linkages between STI and ODA***

104. Among the key barriers that hinder cooperation between STI and ODA sector is the lack of a common measurement standard that could be used internationally to define and measure so-called 'ODA-based STI' or 'STI-based ODA'. Common standards are necessary to collect relevant statistics on STI-based ODA programs, to coordinate stakeholders from both STI and ODA communities, and to develop new national agenda on promoting STI for sustainable development. Further enhancements of DAC statistical systems are need to more granular assessments of ODA-eligible research and to explore

the share of resources, which strengthen developing countries' STI capacities. Measurement approaches will also need to consider a performance/beneficiary perspective than a funder/donor one.

105. Other barriers that impede collaborations and information sharing between STI and the ODA communities include:

- *Difficulty in integrating STI into development cooperation context*: While development co-operation aims at promoting sustainable socioeconomic development in less developed countries, STI emphasises creating new and innovative knowledge and achieving scientific and economic competitiveness; therefore, STI policy makers tend not to consider social inclusiveness and global challenges as important as science excellency and economic growth. Higher education institutions tend not to view 'responsible research and innovation' as their primary missions such as education and research. Both communities should try to strengthen communication, policy alignment and coordination to facilitate the 'STI for sustainability

- *Complexity of global partnerships with multi-stakeholders*: STI initiatives for sustainable development requires building international partnership with multi-stakeholders including government, research councils, higher education institutes, firms and industries, civil communities and global philanthropies. However, it is difficult to developing effective partnership model with a wide range of disciplinary knowledge to address global issues and equitable engagement of the development agenda by all relevant stakeholders.

- *Need demand-lead approach of innovation system in developing countries*: There are many gaps between donor countries and beneficiary countries in terms of social infrastructure, level of technology development and government capabilities. Demand-led approach is more effective to improve innovation system in developing countries through equitable partnership that empower institutions and researchers in developing countries to participate more equitably in co-design, co-creation and co-implementation of development initiatives in STI.

- *Leveraging ODA funding for research for development and developing* The ODA community struggles to increase the share of direct funding programmes for research and innovation activities. Joint programmes between ODA funds and R&D funds such as the UK Global Challenges Research Fund are one way to leverage funds as well as co-funding with philanthropies and business.

- *Tensions between research which is focused on excellence and research which is focused on providing solutions to developmental problems.* The immediacy of development goals requires more applied research and solutions as opposed to longer-term research projects. New evaluation criteria are also needed in order to measure the impact of research for development. The Swiss Agency for Development and Cooperation (SDC), a part of the Federal Department of Foreign Affairs has set aside principles for investment of ODA funds in research in order to address some of these tensions. ODA funding for research activities should be*:*

  (i) Related to SDC's long-term strategic objectives and thematic priorities

  (ii) Promotion of research geared to solutions and applications

  (iii) Strong scientific quality and development relevance

(iv) Research freedom, competitive calls

(v) Research findings to actively communicated, disseminated and applied, open access principles

(vi) Research carried out in partnerships

- *Need to include support to STI infrastructure, both physical labs and data infrastructure in STI –ODA.* From the perspective of developing countries, support for infrastructure such as laboratories and science and technology parks (STP) which can facilitate the creation of new jobs and business via incubation and spin-off mechanism are necessary. However, there are limited funds spread across competition priorities rarely able to invest in STP. Middle-income countries such as Thailand are taking a pragmatic approach to linking STI and ODA policies by focusing on achieving shared understanding with partners and delivering mission-oriented projects with clear goal and implementation mechanism.

5.

6. ***Beyond linking STI and ODA programmes***

106. There remain several open questions regarding how to co-operate with developing countries inside and outside the domain of ODA. The technological gap between developed and developing countries remains a big challenge. However, the current wave of frontier technologies can provide new opportunities to enhance the role of ODA and global STI partnership for SDGs. For example, ICT technologies such as artificial intelligence, big data and block-chain technology can play an enabling role in the implementation of development assistance by developing a deep understanding of the specific needs of individuals and groups in developing countries. In order to benefit from frontier technologies, it is also important to improve the capabilities of governments in developing countries to ascertain the potential of frontier technologies in their specific context.

107. The emerging STI collaboration model between OECD and developing countries should take into account the demand side in beneficiary countries and the supply-side in donor countries as well as the role of the international system (UN, development banks and multilaterals). It is important for universities on both sides to expand their role not only in research and education but also in the field of global engagement. For this to occur, the STI and ODA policy communities should promote mutual understanding, define right questions to address, co-design the way of collaboration, integrate research for development, and create the necessary enabling environment.

1.12. Section Summary

108. Many donor countries and private philanthropies are making efforts to promote STI in ODA, which range from allocating a portion of national public R&D to ODA investment, to promoting research funding programmes for development, supporting dedicated centres and institutions, and strengthening multi-stakeholder partnership with recipient countries. However, there are still challenges and obstacles that hinder collaboration between STI and ODA sector. One of the key barriers is the lack of international measurement standard to define the STI component in ODA, to collect and share relevant policy data, and to monitor and evaluate the performance. Other challenges include different policy context between STI and ODA, complexity of global multi-stakeholder partnership, socio-economic and technological gaps between donors and recipients, and limited research funds for development including especially funds for STI

infrastructure in developing countries. Differences in evaluation criteria between research excellence and developmental impact also have to be addressed. Co-operation with NGOs, local community partners and business is particularly important in the context of ODA and it is important for the STI community to draw lessons from the expertise of the aid community.

109. Developing countries can benefit from the current proliferation of low cost ICT technologies. For this to occur, development assistance needs to integrate the demand-side and of the specific needs of stakeholders in developing countries. Meanwhile co-operation should help developing countries invest in national capabilities to utilise existing frontier technologies. ODA funding for STI must also consider the need to develop infrastructure in developing countries both for science (laboratories) but also for innovation (science and technology parks, incubators and start-up accelerators). This represents an important shift in capacity building policies as at present most STI-related ODA goes to support research activities.

References

Borrás, S. and C. Edquist (2013), "Borrás, S. and Edquist, C. (2013). The choice of innovation policy instruments.", *Technological forecasting and social change, 80(8)*, pp. 1513-1522. [23]

Caroline S Wagner, L. (2005), "Network structure, self-organization, and the growth of international collaboration in science", *Research Policy*, pp. 1608-1618. [3]

De La Mothe, J. (2004), "The Institutional governance of technology, society and innovation", *Technology in Society*, Vol. 26, pp. 523-536, http://dx.doi.org/10.1016/j.techsoc.2004.01.009. [33]

Edler, J. and W. Boone (2018), "Next Generation Innovation Policy and Grand Challenges", *Science and Public Policy (Special Issue)*. [22]

Edler, J. and J. Fagerberg (2017), "Innovation policy: what, why, and how. Oxford Review of Economic Policy", *Oxford Review of Economic Policy*, pp. 2-23. [25]

Edler, J. and L. Georghiou (2007), "Public procurement and innovation—Resurrecting the demand side", *Research policy, 36(7)*, pp. 949-963. [24]

Edquist 2012, Z. (2012), . [15]

Ergas, H. (1987), "Does technology policy matter.", *Technology and global industry*, pp. 191-245. [16]

European Commission (2016), *Science, Research and Innovation performance of the EU*, http://dx.doi.org/10.2777/427046. [4]

Foray, D. and D. Mowery (2012), "Public R&D and social challenges: What lessons from mission R&D", *Research Policy 41(10)*, pp. 1697-1702. [14]

Gassler, H., W. Polt and C. Rammer (2007), *Priority Setting in Research & Technology Policy: Historical Developments and Recent Trends,*. [17]

Henneman, S. and E. al. (2012), "The Myth of Global Science Collaboration : Collaboration in epistemic communiities", *Journal of Informetrics 6 (2)*, pp. 217-225. [8]

Junkers and Cruz (2010), "Internationalisation of public sector research through joint laboratories", *Science and Public Policy*, Vol. 37/8, pp. 559–570, http://dx.doi.org/10.3152/030234210X12767691861056. [2]

Kuhlmann, S. and A. Rip (2016), *How the Norwegian research system could cope with grand societal and economic challenges.*, Research Council of Norway. [12]

Kuhlmann, S. and A. Rip (2014), *The Challenge of Addressing Grand Challenges. A think piece on how innovation can be driven towards the "Grand Challenges" as defined under the prospective European Union Framework Programme Horizon 2020*, European Commisson. [20]

Lindner, R. et al. (2016), *Lindner, R., Daimer, S., Beckert, B., Heyen, N., Köhler, J., Teufel, B., Warnke, P., Wydra, S. (2016). Addressing directionality: Orientation failure and the systems of innovation heuristic. Towards reflexive governance. Discussion Papers Innovation Syste*, Fraunhofer. [13]

Loet Leydesdorff, C. (2008), "International Collaboration in science and the formation of a core group", *Journal of Informetics*, pp. 317-325. [5]

Mazzucato, M. (2015), *Mazzucato, M. (2015). A mission-oriented approach to building the entrepreneurial state. Report Commissioned by UK Government*, United Kingdom Government. [21]

Mowery, D. et al. (2010), "Technology policy and global warming: Why new policy models are", *Research Policy 39*, pp. 1011–1023. [11]

NCSTE and Clarivate Analytics (2017), *China's International Scientific Research Collaboration*. [7]

OECD (2017), *OECD Science, Technology and Industry Scoreboard 2017: The digital transformation*, https://doi.org/10.1787/9789264268821-en. [9]

OECD (2016), *DSTI/STP/TIP(2016)12/REV1*, OECD. [31]

OECD (2016), *OECD Science, Technology and Innovation Outlook 2016*, http://dx.doi.org/10.1787/25186167. [28]

OECD (2016), *Science, Technology and Innovation Outlook*, OECD. [29]

OECD (2015), *Inclusive Innovation Policies for Inclusive Growth*, OECD ISBN:9789264237025 (EPUB); http://dx.doi.org/10.1787/9789264229488-en. [30]

OECD (2014), *Research Co-operation between Developed and Developing Countries in the Area of Climate Change Adaptation and Biodiversity*, OECD. [26]

OECD (2011), *Attractiveness of Innovation: Location Factors for International Investment*, OECD. [32]

OECD (2010), *Background and Issues Paper for the CSTP Workshop on Green technology and innovation [DSTI/STP/AH(2010)1]*, OECD. [19]

ROUND TABLE ON SUSTAINABLE DEVELOPMENT (2018), *Background Paper for the 37th Round Table on Sustainable Development; Accelerating the development and diffusion of low-emissions innovations*. [27]

Royal Society (2016), *UK research and the European Union The role of the EU in international research collaboration and researcher mobility*. [10]

Schwaag, S. and S. Remoe (2014), *International Cooperation in Science, Technology and Innovation*, European Commission . [1]

Shashnov S, A. (2018), “Research landscape of the BRICS countries: current trends in research output, thematic structures of publications”, *Scientometrics (2018)*, Vol. 117/2, pp. 1115–1155, https://doi.org/10.1007/s11192-018-2883-7. [6]

Smith, K. (2017), “Innovating for the global commons: multilateral collaboration in a polycentric world”, *Oxford Review of Economic Policy, Volume 33, Number 1*, pp. 49-66. [18]

Annex Table 1. International Funds for Grand Challenges

Country	***UK***	***Denmark***	***Norway***	***Switzerland***	***Germany***	***Canada***	***China***
Fund Name	*The Global Challenges Research Fund (GCRF)*	*The IFD Grand Solutions Programme (IFDGSP)*	*The Norway Global Partner (NORGLOBAL)*	*The Swiss Programme for Research on Global Issues for Development (r4d programme)*	*Research for Sustainable Development (FONA3)*	*Grand Challenges Canada (GCC)*	*Green Technology Bank (GTB)*
Responsible Ministries	*The Department for Business, Energy and Industrial Strategy (BEIS)*	*The Ministry of Higher Education and Science (MHS)*	*Norwegian Ministry of Foreign Affairs (MFA), Norwegian Agency for Development Cooperation (Norad)*	*the Swiss National Science Foundation (SNSF), The Swiss Agency for Development and Cooperation (SDC)*	*The Federal Ministry of Education and Research (BMBF)*	*Global Affairs Canada*	*Ministry of Science and Technology (MOST), Shanghai Municipal People's Government*
Launch time	*2015*	*2015*	*NORGLOBAL-2 (2017-2024), First started at 2009*	*2012*	*FONA3 (2015-2019) First started at 2005*	*2017 with new vision First started at 2010*	*2016*
Type	*Departmental funds*	*Departmental funds*	*Cross-departmental funds*	*Cross-departmental funds*	*Departmental funds*	*Departmental funds*	*Cross-departmental funds*
Objectives	***Promoting UK research excellence****: "to ensure UK science takes the lead in addressing the problems faced by developing countries, whilst developing our ability to deliver cutting-edge research".* ***Resolving global development challenges****: "to generate innovative solutions to*	***Stimulate the Denmark Growth and employment, and Solutions to key societal challenges.*** *Invests in collaborative projects and partnerships at different stages across the value chain with the aim for*	***Research-based knowledge*** *of high quality on poverty reduction and sustainable development informing development policies, development programmes, private*	***To generate*** *scientific knowledge and research-based solutions for reducing poverty and global risks in least developed low- and middle income countries.* ***To offer*** *national and international stakeholders methods and options for finding integrated, holistic*	***To support innovations for a more sustainable society.***	***Optimize*** *the impact of Grand Challenges Canada's existing pipeline of seed and Transition To Scale development innovations.* ***Build*** *new pipelines of development and humanitarian innovations in greenfield areas and*	***Aim to*** *gather advanced green technologies, scale up low-carbon solutions for development challenges and promote transfer of innovative technologies to developing countries.*

Country	UK	Denmark	Norway	Switzerland	Germany	Canada	China
Fund Name	*The Global Challenges Research Fund (GCRF)*	*The IFD Grand Solutions Programme (IFDGSP)*	*The Norway Global Partner (NORGLOBAL)*	*The Swiss Programme for Research on Global Issues for Development (r4d programme)*	*Research for Sustainable Development (FONA3)*	*Grand Challenges Canada (GCC)*	*Green Technology Bank (GTB)*
	intractable development issues and to identify practicable pathways to healthier and safer lives, sustainable development and prosperity for all, equal and effective education, social justice and human rights, and stable institutions".	*stimulating economic growth, creating jobs and solving societal challenges. Also invests in 'opportunity-driven' research and innovation in emerging fields.*	*sector investments and further research.* ***Support progress towards** implementing the United Nations Sustainable Development Goals (SDGs).*	*approaches to solving problems.* ***To enhance** scientific skills and know-how in dealing with the complexity of global problems for the benefit of societies in developing and emerging countries.*		*transition to scale the most promising solutions.* ***Incubate** the Indigenous Innovation Initiative.* ***Grow** Grand Challenges Canada's reputation and capabilities, both globally and domestically, as a resource and platform for innovation with impact.*	
Priority setting							
Focus Challenge or SDGs	*12 challenge areas organized under 3 themes contribute to success of all 17 UN SDGs*	/	*Several SDG-related areas in geographical prioritisation of Norwegian development.*	/	/	/	*As a key initiative of China to implement the UN 2030 Agenda for SDGs, mainly on green technology*
Priority areas	· *Equitable access to sustainable development* · *Sustainable economies and societies* · *Human rights, good governance and social justice*	· *Bioresources, food and lifestyle* · *Biotech, medico and health* · *Energy, climate and environment* · *Trade, service and society* · *Infrastructure, transport and production* · *Production, materials, digitisation and ICT*	· *Global education* · *Humanitarian efforts* · *Conflict, security and fragile states* · *Business development and job creation* · *The environment, climate and renewable energy*	· *Causes of and solutions to social conflicts in contexts of weak public institutions* · *Employment in the context of sustainable development* · *Innovation in Agricultural and Food Systems for Food Security* · *Sustainable Management of Ecosystems for the Provision of Ecosystem Services* · *Provision systems and financing mechanisms in the public health sector*	· *Flagship initiatives for sustainability (Green Economy, City of the Future, the Energiewende – Germany's transformation of its energy system)* · *Prevention research for sustainability (Maintaining and enhancing quality of life and competitiveness, Using resource intelligently and efficiently, Protecting common assets: climate, biodiversity and the*	· *Development (Transition To Scale, Stars in Global Health, Saving Lives at Birth, Saving Brains, Global Mental Health, The Water Innovation Engine)* · *Humanitarian (Creating Hope in Conflict)* · *Indigenous (Indigenous Innovation Initiative)* · *Other initiatives (Global Health Investment Fund, Every Woman Every Child Innovation Marketplace, Kangaroo Mother Care Development Impact Bond)*	· *Integrate S&T and finance, realizes the capitalization of S&T achievements, and accelerates the transfer of S&T achievements, transformation, and industrialization especial in the resource conservation and saving, environmentally friendly, safety, and efficiency, life and health as well as other sustainable development areas.*

Country	UK	Denmark	Norway	Switzerland	Germany	Canada	China
Fund Name	*The Global Challenges Research Fund (GCRF)*	*The IFD Grand Solutions Programme (IFDGSP)*	*The Norway Global Partner (NORGLOBAL)*	*The Swiss Programme for Research on Global Issues for Development (r4d programme)*	*Research for Sustainable Development (FONA3)*	*Grand Challenges Canada (GCC)*	*Green Technology Bank (GTB)*
					ocean, Education and research: working together for sustainable development)		
Priority countries	*All countries on the OECD's list of ODA-eligible countries, whether low- or middle-income.*	*Open to all countries.*	*All low- and lower-middle income countries (LMIC) not included South Africa, India, China and Latin America which have been supported in other bilateral programmes.*	*least developed, low income or lower middle income countries (DAC list of OECD)*	*European cooperation: countries in European programme Horizeon 2020. International Partnerships for Sustainable Innovations (CLIENT): Particularly in the emerging markets and developing countries. International cooperation in prevention research: open to all countries*	*low- and middleincome countries*	*Open to all developing countries, as well as a comprehensive service platform for South-South cooperation*
Governance							
Decision-making body	*BEIS Research and Innovation ODA Board (Newton Fund and GCRF)*	*Board of IFD*	*Programme Board Appointed by the Research Board for the Division for Society and Health of the*	*The Steering Committee The SDC and the SNSF are equally represented in the Steering Committee.*	*/*	*Board of Directors*	*GTB leading group*

Country	UK	Denmark	Norway	Switzerland	Germany	Canada	China
Fund Name	*The Global Challenges Research Fund (GCRF)*	*The IFD Grand Solutions Programme (IFDGSP)*	*The Norway Global Partner (NORGLOBAL)*	*The Swiss Programme for Research on Global Issues for Development (r4d programme)*	*Research for Sustainable Development (FONA3)*	*Grand Challenges Canada (GCC)*	*Green Technology Bank (GTB)*
			Research Council of Norway (RCN)				
Advisory body	*GCRF Strategic Advisory Group*	/	/	*The International Advisory Board*	/	*The Scientific Advisory Board*	/
Implementing body	*Research Councils UK (RCUK), Higher Education Funding Councils for England (HEFCE),UK Space Agency (UKSA), and National Academies*	*The Innovation Fund Denmark (IFD)*	*The Division for Society and Health of RCN*	*The Swiss National Science Foundation (SNSF)*	*Funding Consulting Research and Innovation of the Federal Government, Project Management Jülich (PtJ), DLR promoter, Project Management Karlsruhe (PTKA)*	*The Grand Challenges Canada*	*Administrative Center for Green Technology Bank*
Monitoring body	/	*The Danish Agency for Institutions and Educational Grants (SIU)*	/	/	/	*The Scientific Advisory Board*	/
Project Management							
Support policy	*Support UK universities and research organizations in undertaking Solutions-focused and Challenge-led research, not give to priority to individual countries*	*The head applicant must be Danish and a significant value must be captured in Denmark.*	*Challenge-based approach. All projects must have outstanding international partners, and with the Norwegian institution as project owner.*	*All projects are carried out within transnational research partnerships. The responsible applicant must be employed at a Swiss research institution. A minimum of 40% of the total project budget must go to the partners in least developed, low and lower middle income countries.*	/	*Funds innovators in low- and middleincome countries and in Indigenous communities in Canada.*	*Integrate S&T and finance, realizes the capitalization of S&T achievements, and accelerates the transfer of S&T achievements to industrialization especial in the field of green technology*
Project selecting	*Bottom-up (Individual calls, Joint calls and Collective Fund calls)*	*Bottom-up (Thematic calls, Open calls, and Societal partnerships)*	*Bottom-up (high-quality research researcher projects and post-graduate level research)*	*Bottom-up*	/	*Bottom-up (includes an independent scientific review, followed by presentation to sub-Committee of the Board and Board of Directors for consideration)*	/

Country	**UK**	**Denmark**	**Norway**	**Switzerland**	**Germany**	**Canada**	**China**
Fund Name	*The Global Challenges Research Fund (GCRF)*	*The IFD Grand Solutions Programme (IFDGSP)*	*The Norway Global Partner (NORGLOBAL)*	*The Swiss Programme for Research on Global Issues for Development (r4d programme)*	*Research for Sustainable Development (FONA3)*	*Grand Challenges Canada (GCC)*	*Green Technology Bank (GTB)*
Funding and Budget							
Support targets	/	*Universities, research institutions, RTOs, public and private companies and government organisations.*	/	*Researchers employed at Swiss research institutions and at research institutions in African, Asian and Latin American countries collaborate.*	*research institutions, universities, companies, municipalities, non-profit-organizations*	/	*Innovative entrepreneurial enterprises, especially small and medium enterprises (SMEs)*
Source	*UK Official Development Assistance (ODA) Funding*	*Granted under the Danish Finance Act*	*Norwegian Ministry of Foreign Affairs (MFA), Norwegian Agency for Development Cooperation (Norad)*	*The Swiss Agency for Development and Cooperation (SDC), the Swiss National Science Foundation (SNSF)*	*The Federal Ministry of Education and Research (BMBF)*	*Global Affairs Canada, Bill & Melinda Gates Foundation, the U.S. Agency for International Development's Office of U.S. Foreign Disaster Assistance(USAID), the U.K. Department for International Development (UK DFID), and the Australian Department of Foreign Affairs and Trade*	*Ministry of Science and Technology (MOST), Shanghai Municipal People's Government, and some other many government-oriented guidance funds*
Budget	*£1.5 billion from 2016 to 2021*	*DKK 3.3 billion from 2015 to 2018*	*NOK 188 million from 2017 to 2021*	*CHF 97.6 million from 2012 to 2022*	*2.1 billion Euro from 2015 to 2019*	*160 million CAD from 2016 to 2025*	*A Green industry fund of RMB3.5 billion*
Implemented projects	/	*169 projects (Jun, 2018), DKK 5-30 million per project, 3 – 5 years*	*136 projects from 2009 (Jan, 2019), Total amount about NOK 433.5 million*	*57 projects in 50 countries (May, 2018)*	/	*1026 projects with 95 countries (from 2010), Total amount about 234 million*	/
Cooperated Fund	*Some UK ODA initiatives including the Newton Fund, the Ross Fund and the Prosperity Fund*	*EUREKA-TURBO Bilaterale with JPI and ERA*	*Some programmes in RCN and ERA-net including FINNUT, Programme on Climate Research (KLIMAFORSK), Programme for Energy research (ENERGIX), Environmental*	/	*The programme-oriented funding (POF) of the Helmholtz Association (HGF), the Max Planck Society (MPG), the Fraunhofer-Gesellschaft (FhG), and the Leibniz Association (WGL)*	*Bill & Melinda Gates Foundation, McConnell Foundation*	*World Intellectual Property Organization (WIPO), UN Department of Economic and Social Affairs (UN DESA), UN Environment Programme (UN EP) and UN Industrial and Development Organization (UN IDO)*

Country	UK	Denmark	Norway	Switzerland	Germany	Canada	China
Fund Name	*The Global Challenges Research Fund (GCRF)*	*The IFD Grand Solutions Programme (IFDGSP)*	*The Norway Global Partner (NORGLOBAL)*	*The Swiss Programme for Research on Global Issues for Development (r4d programme)*	*Research for Sustainable Development (FONA3)*	*Grand Challenges Canada (GCC)*	*Green Technology Bank (GTB)*
			Research for a Green Transition (MILJØFORSK)				
Evaluation							
Yes/no	*Yes (Rapid review by ICAI)*	*Yes*	*No*	*yes*	*yes*	*yes*	*No*
Time	*Sep, 2017*	*July, 2018*	*Will be evaluated by the end of 2020*	*Nov, 2017 Mid-Term Review*	*Ongoing Evaluation (FONA since 2005): Results in January 2019*	*Review every year*	*/*
Internal /external	*External Independent commission for Aid Impact (ICAI)*	*Internal self-evaluation*	*External independent experts*	*External Universalia from Canada*	*/*	*External The Scientific Advisory Board*	*/*
Web site	*https://www.ukri.org/research/global-challenges-research-fund/*	*https://innovationsfonden.dk/en/programmes/grand-solutions*	*https://www.forskningsradet.no/prognett-norglobal/About_the_programme/1224698160120*	*http://www.r4d.ch/r4d-programme*	*http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=views;document&doc=8984*	*https://www.grandchallenges.ca/who-we-are/*	*http://www.greentechbank.com/greentech/web/aboutus/en/aboutusIndex*