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Foreword

On 30 January 2020, the World Health Organisation declared the COVID-19 outbreak a Public Health Emergency of International Concern, which was the signal for an unprecedented mobilisation of the science community across the World. The pandemic has been not only a massive public health crisis but has affected all socio-economic sectors and all countries and changed many aspects of people's daily lives in a permanent manner. It has also changed many views on the roles of science and the way that it operates. Whilst the rapid development and deployment of effective diagnostic tools and vaccines, has enabled most countries to emerge from the crisis and envisage a future living with COVID as a manageable endemic disease, there are many lessons that need to be learned to improve the resilience of science systems. The world is already in the midst of another complex global crisis that calls for rapid socio-economic transitions. New knowledge and new technologies are urgently required to address the challenges of sustainable development and environmental change and critical analysis of how science responded to COVID-19 should ensure that countries are better prepared to meet these challenges.

This is the final report in a series of three, exploring how science was mobilised in response to COVID-19 and the lessons that we can learn from this for the future. Report 1 focuses on 'policy for science' and critical elements of science systems – data and information, research infrastructures and public-private partnerships. Report 2 focuses on 'science for policy and society' and key activities at the interface between science, policy and society – agenda setting, scientific advice and public communication and engagement. This 3rd report explores cross-cutting meta-issues and discusses their implications for resilience and transitions. The relation between the interventions for resilience and required actions that are proposed for each meta-theme in this report and the more specific policy options that are included in reports 1 and 2 is shown in annex 1. The context in each country is different and so the priority attached to these interventions and options will vary. They are provided as an overall framework for science policymakers and other actors, including research funders and research providers, to consider. They can also be a starting point for national assessments of how science performed during COVID and how systems might be adjusted to respond more effectively to ongoing and future crises.

The "Mobilising science in response to crisis: lessons learned from COVID-19" project was initiated in October 2020 – several months after the start of the pandemic – and was conducted under the aegis of the OECD Global Science Forum (GSF).

Acknowledgements

This work was overseen by an international group of experts from 12 countries (see annex 2) and drew on input from a broader group of experts from policy and research, who were directly involved in the pandemic response in different contexts and contributed to a series of virtual workshops (see annexes 3 and 4). Without these people, who made time to contribute in the midst of the crisis, this project would not have been possible. This report, and the other two report in this series, were drafted by Jessica Ambler, working as a consultant to OECD, and edited by Carthage Smith, Head of the GSF Secretariat. The Expert Group and other members of the GSF secretariat – Frederic Sgard and Yoshiaki Tamura - provided critical input.

Executive Summary

Resilience can be defined as “the ability to resist, absorb, recover from or successfully adapt to adversity or a change in conditions” (Linkov, 2017[1]) and it needs to be evaluated in relation to the politics, interests, and intentions with which national systems (science, health, or otherwise) are mobilised (WHO, 2021[2]). Resilient science systems are a critical foundation for resilient societies. The COVID-19 pandemic has been an unprecedented global crisis, the scientific response to which has revealed both strengths and structural weaknesses in the resilience of science systems. Moreover, the way in which the pandemic has evolved to impact all sectors of society has emphasised the importance of systems thinking for addressing interconnected risks across multiple dimensions. While many countries have benefited from the ability to leverage established science capacities to tackle specific risks, this has not always been enough to effectively address the systemic issues, which have characterised the pandemic.

Effective response to the pandemic has required the co-ordination, co-operation, and collaboration of diverse actors across scientific disciplines, policy domains, sectors, and jurisdictions. However, these actors bring with them differing expectations, motivations, and perspectives. In a similar way, complex societal challenges, such as climate change, are also generally characterised by interdependencies, uncertainties, circularities, and conflicting stakeholder views (Svensson, Khan and Hildingsson, 2020[3]) (Rittel and Webber, 1973[4]). Such tensions are inherent to the processes and structures of science and how they interface with policy and the public, across different geographic scales.

The urgent requirement for new knowledge and technologies to respond to the COVID-19 pandemic has demanded much more than ‘business as usual’ from science systems, and new science policy initiatives have played an important role in mobilising different actors within these systems to address different priorities. At the same time, being able to leverage already existing mechanisms, good practices, and social capital has been essential for researchers and science policymakers to respond effectively. Whilst each crisis is unique, a critical assessment now of the scientific response to the pandemic can provide important and actionable insights into what will likely be required to respond more effectively to future crises. There is a window of opportunity now to learn from COVID-19 to improve the resilience of science systems.

This document is the final publication in a trilogy of policy reports developed as part of the OECD-GSF project, *Mobilising Science in Response to Crises: lessons learned from COVID-19*. The overall aim of the project has been to distil the content from a series of 6 international workshops and other data and published materials into learnings regarding the mobilisation of national and international science systems in response to the pandemic. These learnings can support policymakers in preparing for, anticipating, responding to and mitigating future crises. They also demonstrate the implausibility of anticipating all the cascading implications of ongoing and future crises before they emerge and hence the importance of focusing on improving systemic resilience.

Challenges, lessons, and good practices identified in this report relate specifically to five ‘meta-themes’. These high-level themes are apparent across the six functional areas discussed in the first two reports of this series: report 1) policy for science – data and information, research infrastructures, and science-industry collaborations – and report 2) science for policy and society – priority setting and co-ordination, scientific advice, and public communication and engagement. Meta-themes relate to: **the strategic mobilisation of science capacity; managing conflicting priorities; co-ordination and collaboration**

across levels of governance; transdisciplinary and reflexive science; and dynamic and system-oriented governance. These meta-themes are interconnected in that they enable each other. This report aims to identify, deconstruct, and examine these points of intersection to draw attention to the structural nature of many of the issues that challenged the scientific response to the pandemic and the similarly structural nature of the points of intervention and actions required to address them.

The main lessons learned under each of the five meta-themes are briefly introduced in the following section of this report and key areas for policy intervention are summarised in Figure 1. More specific policy actions corresponding to each of these areas for intervention are presented at the end of each of the subsequent sections in the report and illustrative case studies are referenced in section endnotes to provide additional context. The challenges, learnings, and good practices discussed in this report are broadly applicable across OECD countries; however, policymakers should interpret them in relation to their specific national context, which will likely influence the relevance and urgency of distinct actions and the design of related policy. Similarly, institutional responsibilities for implementing the required actions will differ across jurisdictions. Intervention points and required actions are provided to assist countries in advancing their science systems to prepare for, respond to, and recover from health pandemics and other complex societal challenges more effectively in the future.

Meta-themes and Recommendations

An effective response to an emerging crisis depends initially on the agile and **strategic mobilisation of science capacity.** The efforts of many countries to respond to the COVID-19 pandemic have demonstrated the need for sustainable, long-term investment into critical elements of science systems, including data and information, research infrastructures, and partnerships. Proactive and strategic efforts have been important to build scientific capacities, to foster synergies, address duplication and gaps, and facilitate the scientific response. Yet, budgetary challenges and lack of political prioritisation have historically impeded sustained public funding for science in many countries and internationally. Keeping science at the technological forefront requires substantial, recurrent investment. In this regard, pandemic has illustrated the enormous importance of digital technologies for sustaining collaborations and improving the visibility and accessibility of science infrastructures, data, and other information assets. At the same time, technology alone has not been enough and skilled and dedicated scientific personal have been essential.

Existing mechanisms and processes have had to be adapted to ensure swift and nimble mobilisation of scientific capacities. In this respect, mutual trust between science policymakers and researcher providers has been key to setting flexible and responsive research priorities, as well as expediting the distribution of funding and the initiation of new, and adaptation of established, research activities. To a certain extent, the 'covidisation of research' through the pivoting of research activities and infrastructure operations has delayed, or otherwise inhibited, research in fields lacking direct relevance to the pandemic (Pai, 2020[5]). Future efforts will be required to mitigate potential long-term impacts on research portfolios and individual researchers.

When responding to a global crisis, it is important that collaboration and co-operation bring together actors from a breadth of countries, scientific disciplines, sectors, and policy domains. However, this raises the need to **manage conflicting priorities** and interests. Differing perspectives must be understood and accommodated to support the development of a broad and balanced evidence base and to ensure the collective development of holistic solutions during crises. There are a multitude of distinct and intersecting dimensions, which science policymakers and scientists must deliberatively consider when establishing priorities for funding, including how, why, and for whom research is undertaken. These elements are not simply objective and require reflexivity (Schmidt, 2011[6]) (Svensson, Khan and Hildingsson, 2020[3]). The COVID-19 pandemic response has brought several issues to the fore, where maintaining an appropriate balance is required: 1) national priorities or prestige and corporate interests, versus pursuit of the global public good; 2) support for research activities aimed at advancing fundamental scientific understanding versus mission-based solutions or short-term returns on investment; 3) adherence to normative standards, such as ethical and legal guidelines while expediting public health research; and 4) conventional communication versus efforts to foster mutual trust and more active engagement at the science-policy-society interface. In a crisis, the balance of these issues may need to change rapidly and substantially, and systems must be prepared to make these changes. This requires built-in resilience and flexibility.

Cultivating global preparedness and resilience requires OECD countries to invest in building the science capabilities of low- and middle-income countries (LMICs) and to prioritise the inclusive development of priorities and multilateral collaborations. The global shock precipitated by COVID-19 has exceeded the capabilities of any single country and has required effective co-operation, **co-ordination, and collaboration across levels of governance.** International bodies, most notably, the World Health

Organisation, have provided guidance and leadership in co-ordinating global action to address various aspects of the pandemic response. Reflection on the actions taken by these bodies and how they were received by individual countries presents a critical learning opportunity. For example, international collaboration has focused primarily on the development of medical countermeasures, i.e., vaccines, therapeutics, and diagnostics. Comparable initiatives related to socio-economic aspects of the response were noticeably lacking, particularly in the early stages of the pandemic, when Public Health and Social Measures (PHSMs) were the only mitigation measures available. Proactive action is required to ensure that international bodies are equipped to lead global efforts to address nascent and forthcoming threats.

Cross-country engagement, often led by the scientific community from the bottom-up, has leveraged international platforms and infrastructures, and joint (often regional) programming mechanisms to address many dimensions of the response. These efforts have made important contributions to the harmonisation and integration of national science activities and assets in some fields. In a similar vein, connectivity between national and subnational science systems and science policy has also been an important enabler of response efforts.

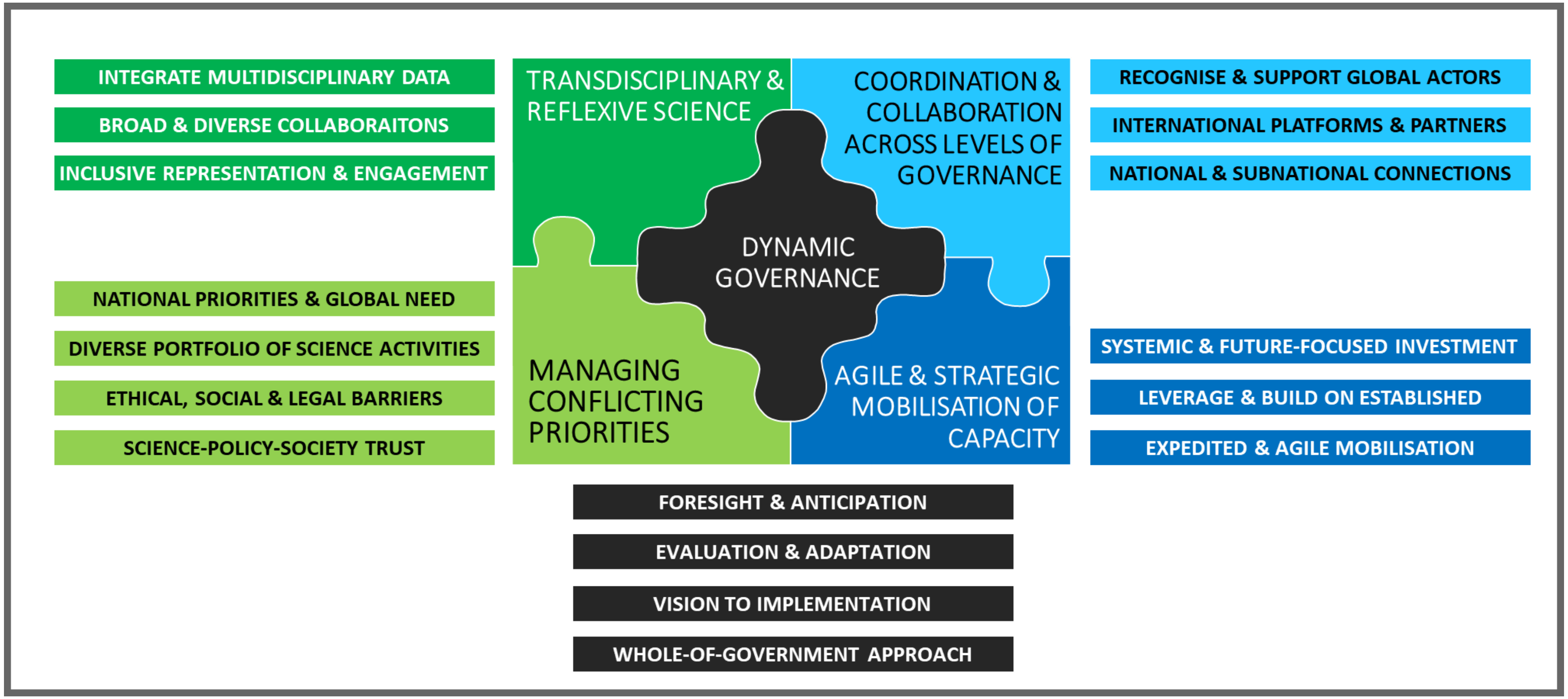
Mobilising, integrating, and contextualising expertise, data, and knowledge from diverse scientific disciplines, sectors, and policy domains is necessary to address the complexity and ambiguity of emerging crises. However, expediting the development of **transdisciplinary and reflexive science** - or even interdisciplinary solutions - has been challenged by the specialised and siloed organisation and operation of many national science systems. In responding to the COVID-19 pandemic, scientists and science policymakers needed to balance swift action with the need to draw on diverse insights to ensure that scientific solutions were broadly informed and appropriately targeted. The ability and willingness of actors to share information and data across scientific disciplines, sectors, and jurisdictions has grown in importance as the complexity and scope of the crisis has increased. While previous efforts to improve data and information access and use, such as the adoption of open science agendas and FAIR (Findability, Accessibility, Interoperability, and Reusability) data principles have provided a valuable starting point, structural barriers, including incentives and practices in academia and commercial publishing, have persisted. In addition, the synthesis of multidisciplinary data into context-specific knowledge requires specialised skills and methodologies, as well as diverse networks, that were generally lacking.

The response to the SARS-CoV-2 outbreak has yielded important insights regarding how innovative business and funding models can be used to promote effective science-industry partnerships. However, policy action will be critical to ensuring that the novel approaches are not forgone during recovery in favour of a reversion to traditional forms of competition. In relation to transdisciplinary collaboration, initiatives in a handful of countries have demonstrated the crucial role that non-governmental organisations, and individual citizens, can play in the development of timely and relevant scientific research and its successful translation into practice. This has perhaps been most notable regarding the adoption and adherence to medical countermeasures and PHSMs. In some countries, public engagement has also been critical to the ethical, transparent, and accountable deployment of novel surveillance technologies. While public engagement in science has been recognised as a priority in many countries, the pandemic response has shown the extent of the gap that exists in making it widespread reality. At the same time, public engagement and communication campaigns aimed at the broad public can inadvertently lead to the exclusion of certain societal groups, including many of those most at risk. COVID-19 has shone a spotlight on this due to the impact that social determinants of health have had on patient outcomes and the extent to which many countries were ill-equipped to draw on disaggregated population data or targeted studies in their response strategies.

Dynamic and system-oriented governance processes and mechanisms are needed in the development of science policies to prepare for, respond to, and recover from crises more effectively. The pandemic has demonstrated this in a number of ways. Mechanisms are needed to translate insights from strategic foresight, and real-time experimental evaluation into policy. Many aspects of the pandemic response were unprecedented and ambiguous and have required a departure from established practices. Where they have been applied, systematic monitoring and evaluation processes have been important for refining policies. In addition, the pandemic has shown the importance of connecting science policy more explicitly to direct beneficiaries, civil society, and other policy domains. Complex societal challenges and crises affect intersections and linkages between different policy domains and invariably require collaboration across these domains to ensure that coherent actions are taken to prepare, respond, and recover from multidimensional threats. Yet, fragmented policy landscapes have posed challenges for many countries during the pandemic response.

In some situations, it may also be necessary to transform established policy development processes to ensure that emerging values, objectives, and visions are effectively reflected and acted upon. For example, there is significant opportunity to use national foresight methodologies to engage scientists and other actors to improve crisis preparedness and response efforts. COVID-19 has underscored the need to integrate foresight and risk assessment capabilities into policy development processes and adapt established structures to deal with hazards that transcend conventional siloes. In a similar vein, the implementation and evolution of many dimensions of the pandemic response, such as PHSMs and vaccine or diagnostic deployment strategies, have neglected to integrate important learnings from previous crisis response efforts and other jurisdictions. While this has not occurred to the same extent in all countries, it has highlighted a dominant culture of policymaking that does not give adequate attention to the insights and improvement opportunities provided by evaluation. There appears to be a disconnect between *ex ante* preparedness exercises, *ex post* evaluation processes, and the translation of learnings into policy action.

Figure 1. Meta-themes and corresponding interventions to improve resilience in relation to complex crises and societal challenges



Note: This figure is a conceptual representation of the meta-themes and interventions addressed in this report. Meta-themes are depicted as the five central puzzle-pieces and interventions are shown as the corresponding color-coded rectangles. Dynamic Governance sits at the heart of the puzzle to represent the importance of structural change in this area as a key enabler of the interdependent transformations required in other areas. Similarly, Managing Conflicting Priorities and Agile and Strategic Mobilisation of Capacity comprise the bottom layer of the puzzle to illustrate the foundation provided to enable Transdisciplinary and Reflexive Science and Coordination & Collaboration Across Levels of Governance. The graphic is intended as a general heuristic to guide policymakers.
Source: Authors' design.

1 Introduction

Ensuring that science and societal systems are resilient.

The COVID-19 pandemic and resulting policy interventions have been a massive and prolonged disruptive force that has affected almost all aspects of a globally interconnected society. Responding effectively has required the rapid production of new scientific knowledge and tools and has served as a real-time test of science systems and their capacity to address a complex societal challenge. Aside from the unique nature of the virus, many of the issues that hindered the ability of science systems to prepare and respond are well known and structural. While these systemic challenges have been accentuated and, at times, exacerbated by the necessary scale, multidimensionality, and urgency of response efforts, many are inherent to the conventional ways in which science systems operate.

The pandemic is a concrete illustration of how science policy and science systems must continue to evolve. This is true in relation to anticipating and addressing new crises, which has historically been the focus of crisis management efforts. However, there has been increasing recognition that the successful prediction and proactive mitigation of nascent threats is extremely challenging as well as being very cost and capacity intensive. In addition, interdependencies and linkages between modern societal systems mean that when crises do occur, there is significant risk that their impact will cascade across multiple dimensions of public life, growing more volatile, uncertain, complex, and ambiguous (Stiehem and Townsend, 2002[7]) (Tõnurist and Hanson, 2020[8]) (OECD, 2020) (OPSI, n.d.[9]). The speed at which the SARS-CoV-2 spread around the globe, effectively shutting down non-essential everyday activities and economic sectors in many countries, exemplifies the vulnerabilities posed by the inter-dependent nature of international systems. At the same time, trends, such as globalisation and digitalisation, which have diminished barriers and facilitated the development of interconnections, present new opportunities for effective crisis management. Exploiting these opportunities requires systems thinking and a greater focus on building systemic resilience.

The pandemic has underscored the need to address longstanding structural issues that limit the effectiveness of science systems in responding to complex crises (see reports 1 and 2 in this series). Preparing for and responding effectively to future crises and other complex societal challenges will require researchers and science policymakers to make strategic, inclusive, agile, and holistic practices the norm rather than the exception. Even now, many countries continue to respond to COVID-19 as it evolves. However, looking back on how the pandemic has unfolded to date provides an opportunity to identify and resolve structural challenges to the effective operation of science systems and foster the resilience needed to prepare for, respond and recover from, future crises and complex societal challenges.

Project Background and Methodology

The project on Mobilising Science in Response to Crises: lessons learned from COVID-19 was launched in October 2020 – several months into the pandemic – and has been overseen by an international Group of Experts nominated by GSF (annex 2). The overarching question that has guided the work is: *What can we learn from the scientific response to the COVID-19 crisis to help science policymakers improve the contribution of science in preventing, preparing for, and responding to future crises?*

The work has focused on identifying challenges, learnings, and good practices through a series of six international workshops (Annex 3). Workshops were organised in partnership with other OECD working parties and organisations and took place virtually from April 2021-April 2022. Workshops focusing on the six key areas that correspond with the first two reports:

1) **Policy for Science**: access to data and information; research infrastructures; science-industry collaborations [the subject of report 1]
2) **Science for policy and society:** priority setting and co-ordination; scientific advice; public communication and engagement. [the subject of report 2]

The workshops were designed to facilitate mutual learning and included a mix of case study presentations, expert panels, and moderated discussion. Background materials, including agendas, videos, and summary reports are available online at https://www.oecd.org/sti/inno/global-science-forum.htm.

Several additional data and information sources have been used to supplement and enrich the insights from the workshops. Data from the OECD Science, Technology, and Innovation Policy COVID-19 Tracker (https://stip.oecd.org/covid/) and the Observatory of Public Sector Innovation (https://oecd-opsi.org/covid-response/) have been analysed. References are made to other OECD, GSF, and academic or grey literature related to the COVID-19 pandemic, crisis response and science systems, as well as resilience and sustainability transitions. The project draws on early analysis of the OECD COVID-19 Tracker data up to the end of 2020 (Paunov and Planes-Satorra, 2021[11]) (Paunov and Planes-Satorra, 2021[12]) Where appropriate, the connection has also been made to an ongoing OECD Science and Technology Policy 2025 initiative, which aims to support policymakers in reforming STI policy portfolios in pursuit of sustainability transitions.

Report Structure

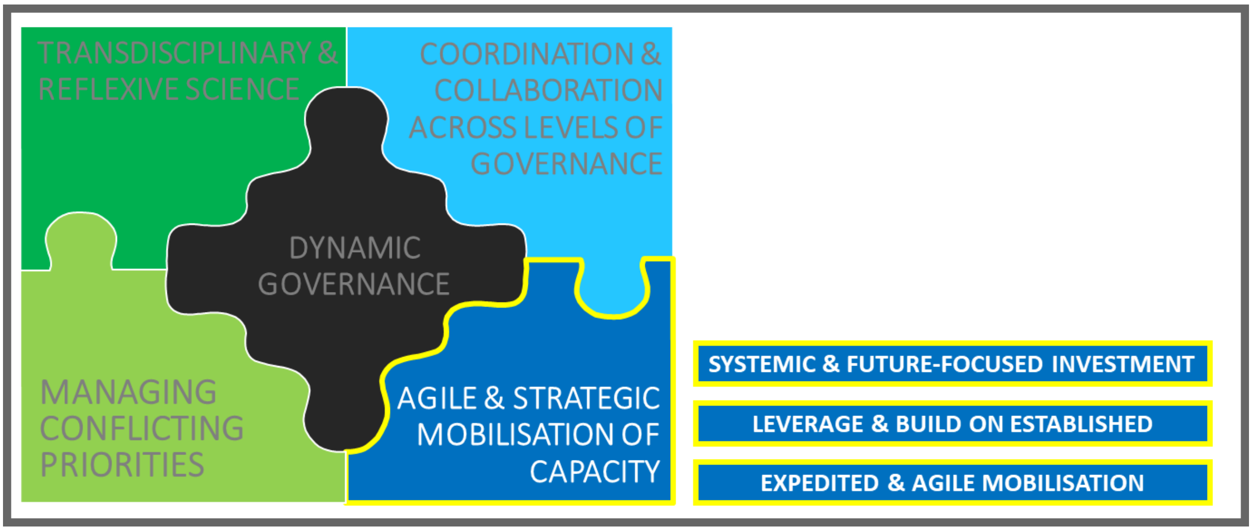
This report is the third in a trilogy of reports of *Mobilising science: lessons learned from COVID-19*. The first two reports focus on COVID-19 as a case study and identify challenges and effective approaches to specific areas of science policy in the context of crisis preparedness and response. This final report, synthesises and builds on learnings in the first two reports and, instead of focusing on the discrete functional areas of science and science policy systems, takes a systems approach to draw attention to interdependencies and linkages between them. The report focuses on five ‘meta-themes’ (see previous section and Figure 1) that across different functional areas and emphasise the structural nature of many of the issues that challenged the scientific response to the COVID-19 pandemic.

A tiered framework of actions is provided in relation to the five meta-themes. These are presented in table at the end of each section of this report in the form of ‘interventions for resilience’ and corresponding ‘required actions’. Interventions for resilience (Fig 1) represent universally critical areas, which require attention from science policymakers to affect the structural changes necessary to improve the resilience of science systems. Required actions represent more specific activities that science policymakers and related actors must take to address the structural issues highlighted. Overlap between the meta-themes, interventions and the more specific policy options identified in reports 1 and 2 are outlined in Annex 1. While the majority of the issues and opportunities raised in this report reflect common experiences across multiple countries, it is recognised that roles and responsibilities, how policies are implemented, and their effectiveness will depend on the national context in which they are applied. Illustrative case studies are included, in endnotes to each chapter, to support policymakers in translating and applying interventions and actions to their local contexts. It should also be noted that at the time of writing, in many parts of the world the response to the COVID-19 pandemic is still ongoing and so the lessons to be learned at this stage are, to some degree, conditional and likely to evolve further.

1 Agile and strategic mobilisation of science capacities

An effective response to an emerging crisis depends initially on the agile and strategic deployment of established science capacity. Timely and co-ordinated action is key to efforts to understand, mitigate, and respond to a threat. This can be enabled by long-term, consistent, and future-focused investment into science systems. Well-tested mechanisms and processes are also important to ensure the swift and nimble mobilisation of science capacities during crises.

Figure 2. Meta-theme: Agile and strategic mobilisation and corresponding interventions



Note: Overview of the interventions proposed for the meta-theme: Agile and strategic mobilisation of science capacities (outlined in yellow).

Taking a systemic and long-term approach to science system investments

The mobilisation of science systems in response to the COVID-19 pandemic has largely depended on the capabilities that already existed. This was true across virtually all aspects of 'policy for science' – access to data, research infrastructures, and science-industry collaborations – and 'science for policy and society' – priority setting and co-ordination, science advice, and public communication and engagement. While novel initiatives and emergency research funding have been introduced, the efforts of science policymakers have predominantly focused on accelerating, co-ordinating, scaling up, and pivoting existing activities and processes. It is critical now that national governments invest proactively in strengthening the data and research infrastructures, capacity, and collaborations required to ensure that all scientific domains can contribute to advancing scientific knowledge and long-term resilience.

The rising prevalence of complex global challenges requires a shift from prioritising short-term financial efficiencies to cultivating strategic redundancies, resilience, and the long-term effectiveness of national science systems. Some countries have made advances in this regard and are now poised to leverage the pandemic as a ‘window of opportunity’ to accelerate change.[1] In the midst of the pandemic response, many countries have announced substantial increases to long-term STI funding commitments. Yet, history has also shown that in the years following a crisis, general and science-related public budgets are apt to decline as residual effects rebound through the economy and society and policymakers choose to divert funding elsewhere (OECD, 2021[13]).

Future-focused and strategic investment into the public research system requires more than the maintenance of funding commitment from Governments. Science policymakers need to transform the processes, methodologies, and tools used to develop science policy. This includes integrating insights from a wider diversity of contributors, including external stakeholders and policymakers from other policy domains (See chapter on dynamic governance). Evaluation also plays an important role here in terms of long-term strategy and crisis response in that it provides policymakers with critical insight into the current capacity and constraints of science systems and their underlying elements, e.g. research infrastructures and public research institutes.

In addition to monitoring and investing in the capacity of the science system it is important that all socio-economic sectors are able to maintain strong connections with public research and assimilate resulting advances as they emerge. Connectivity and mutual exchange between science and non-science policymakers can facilitate the swift integration and uptake of scientific insights and innovations in relevant sectors (See the chapter on dynamic governance for more detail). In this regard it is notable that the uptake of research results during the COVID-19 pandemic response has been challenged by the chronically underfunded nature of the public health sector in many countries and the belated adoption of new technologies and innovations.

Digital technologies have a critical role to play in improving disease surveillance and monitoring. For example, the current state of technological advancement allows for the development of integrated information systems capable of methodical and automated collection of up-to-date data and expedited analysis using machine learning and other analytical tools (Osterhaus, 2020[14]). However, the use of such systems to monitor the risk of an infectious disease outbreak continues to be rare. Some countries have made significant progress in updating and connecting disparate data collection systems to enable this. Israel, Singapore, New Zealand, and Korea were all able to leverage and integrate data from a variety of sources to support contact tracing efforts (WHO, 2021[2]). On the other hand, many countries have faced barriers related to the decentralised and fragmented nature of the public healthcare system and a lack of interoperability in the infrastructure, software, and methodologies being used to collect, store, and share patient records and other data. [2]

International efforts to evaluate the resilience displayed by national health systems during the COVID-19 pandemic have yielded important learnings at the STI-public health interface. Among these are the need to better exploit digital health technologies and co-ordination tools and to advance the global ‘One Health’ agenda (WHO, 2021[2]). The One Health approach requires strengthened co-operation across areas of animal, human, and environmental health and a critical important aspect of this is sharing data and expertise across sectors.

Leveraging and building on established capacities to improve the agility and adaptability of science systems

Human capacity and skills are critical for scientific advancement and improving the resilience of science systems and society more broadly. The speed, scale, and intensity of the pandemic emphasised the increasingly precarious nature of human resources in public research systems. Response efforts have been impacted by deficits in specialised skillsets and expertise and, more systematically, by growing uncertainty regarding the long-term career prospects for early-career researchers. Challenges related to attracting and maintaining qualified scientific, managerial, and administrative expertise have persisted despite being a consistent feature of analyses undertaken over the past decade by the OECD and other organisation (OECD, 2021[15]) s. A variety of factors have contributed to this, including an increasing dependence on short-term project funding and perverse incentives for both research institutions and individual researchers (ICRI, 2021[16]). Long-term strategies and funding commitments are required to support the future development and retention of researchers and research support professionals in academia and the public sector. Targeted policy action is required to build and maintain skills that are important in crisis response, ranging from specialised skills for secure handling of dangerous agents to more general public communication skills.

Many research institutions and individual scientists were motivated by the urgency of the COVID-19 pandemic response to adopt high-intensity work schedules, operating beyond normal capacity and in demanding environments in the early days of the crisis. While this high level of commitment undoubtedly contributed to the unprecedented speed of scientific advancements, the prolonged nature of the stress experienced by many within both science and public health systems may have long-term implications. This is concerning when considered in the context of the precarity under which many professional scientists operate (OECD, 2021[15]). Some countries made efforts to ease the pressure on researchers during the pandemic[3] , including the introduction of targeted support for early career researchers.[4] In the wake of the pandemic, it will be important for science policymakers to introduce similar measures to prevent an exodus from the public research system of those disproportionately impacted by the pandemic.

An important trend that the pandemic response has accelerated is the adoption of digital technologies within government and national science systems, across industry, and in different economic sectors, including public health systems.[5] Digital platforms have been key to ensuring that the regular operations of many research infrastructures and institutes could continue. They have enabled researchers to work collectively and have facilitated, access to and use of research data and results. Moreover, digital tools, such as social media, have created opportunities for widespread two-way communication and engagement between the public, scientists, and policymakers. Enabling digital technologies, such as machine learning and Big Data capabilities have contributed important advancements in public health monitoring and surveillance and have also allowed researchers to maintain an awareness of, and build on, the latest scientific advancements. Technological platforms in specific scientific fields, such as genomic sequencing and synthetic biology, have played central role in the response to the pandemic. However, advocates note that it is important to scale-up related capacity prior to crises, because unless it is already at a sufficient level, it can be difficult to use effectively. Some countries stand out in the regard, such as South Africa, which has experienced a more than fivefold increase in genomic sequencing capacity since the start of the pandemic.[6]

As key players in the initial development and use of many novel technologies, scientists and science institutions have important roles to play in their governance. For example, the role played by digital technologies in many aspects of the pandemic response has illustrated the need for researchers and science policymakers to effectively anticipate and help mitigate the risks and challenges that correspond with these technological advancements. In many countries, policymakers introduced new legislation to address concerns regarding the risks to individual privacy and security posed by advanced contact tracing and surveillance programmes introduced during the pandemic (OECD, 2020[17]). The data from such programmes was potentially an invaluable resource for research to understand the spread of the pandemic but ensuring the safe and secure conditions for its analysis was critical for public trust.

The use of digital technologies for data collection and public communication and engagement has risked exacerbating exclusion and the 'digital divide'. In many respects, digital technologies, such as social media platforms, have also posed significant challenges to national pandemic response efforts by enabling and accelerating transmission of misinformation (OECD, 2021[18]). As the pandemic response transitions to recovery, it will be important that policymakers continue to prioritise the integration of advanced technologies, such as digital innovations, into the operations of science systems to maximise their resilience. This will also mean taking action to anticipate, mitigate, and address related risks, such as cyber-security, and unintended consequences, such as misinformation and exclusion.

Enabling the expedited and agile mobilisation of existing and new resources during crisis response

Structural disconnects between policymakers, scientists, and frontline health workers in many countries translated into the misalignment of political action, scientific evidence and public health operations during the pandemic response (Wu et al., 2021[19]). Research funders struggled to quickly assemble and implement research agendas that would adequately address emerging aspects of the crisis and corresponding policy issues. To a certain extent, this is a function of the differing practices and expectations of scientific and policy domains and the limited experience of researchers and policymakers in working jointly to guide the development of strategy in a difficult and rapidly evolving environment (Choi, 2005[20]). Lack of mutual participation in emergency preparedness and planning exercises prior to the pandemic was a missed opportunity to establish trust and understanding between scientists, policymakers and crisis managers.

In the early days of the pandemic response, there were many instances where the academic community took the lead, acting relatively independently to establish research priorities. While this enabled swift action, ensuring a strategic response has also required scientists to be knowledgeable of policy development processes and needs. Most importantly, it has required co-ordination and implementation of priorities across disparate science agencies and domains. Trends towards specialisation, decentralisation, and competition have made some science systems ill-equipped to realise this level of co-ordination, particularly in situations like the COVID-19 pandemic, where urgent action was required across a broad range of scientific disciplines (OECD, 2018[21]). Future work is required to foster agile, interdisciplinary agenda setting mechanisms and prioritise the integration of social and policy imperatives into scientific research agendas.

To accelerate the distribution of funding during the pandemic, policy-makers and research funders have leveraged existing programmes as well as developing novel initiatives.[7] Special concessions were adopted to allow projects to start work prior to the formalisation of contracts and to incentivise and enable researchers to repurpose ongoing activities in alignment with more urgent needs.[8] Some agencies and research institutes were also able to access earmarked funds following the designation of the outbreak as a public health emergency. There is little doubt that these exceptional measures have contributed to significant success in certain aspects of the scientific response, such as vaccine development. Regardless of this, the response has emphasised that traditional funding mechanisms are often too slow and/or conservative to support certain activities. Science-industry partnerships and unconventional forms of collaboration were challenged to fit into the narrow parameters of public research funding calls. Novel approaches are needed to overcome the biases and tensions inherent to the inclusive collaborations that are necessary to respond effectively to complex and multidimensional societal challenges.

Despite the early focus on biomedical infrastructures and resources, responding effectively to the COVID-19 pandemic has required and ultimately catalysed the adaptation and realignment of activities across all disciplines. In this respect, research infrastructures (RIs) have played an important strategic role. RIs are service-oriented and versatile by nature and these features, combined with the technical and digital capabilities of RIs, enabled them to adapt rapidly and align their operations with emerging policy, scientific, and societal needs (OECD, 2017[22]). In some cases, this has been the result of the initiative taken by individual RIs to pivot their operations, while in others, cross-infrastructural workflows were exploited to support scientific activities of relevance to the pandemic response.[9] The versatility of RIs can improve the overall agility of science systems. However, many RIs have been challenged with the need to accommodate new users and applications while also maintaining support for established high-priority research activities that may not have direct relevance to the crisis response.

The ability of RIs to pivot operations during crises and support activities beyond established mandates is limited by financial and human resources. Even RIs operating in fields of direct relevance to the COVID-19 pandemic were challenged by capacity constraints. In this respect, tried and tested mechanisms have been critical to enable their internal reallocation of resources and allow access to, or application for, additional funding outside established funding cycles. Regular engagement and collaboration between RIs and other actors within and outside of science systems can also facilitate more efficient deployment of available capacity across infrastructures and institutes.

Even in optimal conditions, there are limits to the activities that can be undertaken by a science system at any one point in time. The COVID-19 pandemic spurred an international trend, referred to by some academics as 'the covidisation of research' (Pai, 2020[5]). Funders and policymakers introduced significant incentives for researchers to pursue research in specific fields, while other areas of enquiry have been relatively neglected. Some countries have introduced supports in some form, such as emergency funds and grant extensions to address delays and other negative impacts of the pandemic on general research activities.[10] However, the high profile of the pandemic and the disruptions it and the related mitigation measures posed to everyday life have drawn attention away from the emergence of other infectious disease outbreaks, many of which have occurred in developing regions. Researchers have speculated that the pandemic has delayed funding commitments to other important areas of public health research.[11] In addition, travel restrictions have resulted in the disproportionate deferral and cancellation of activities in many areas. Many countries cancelled research field work in 2020 and 2021 to limit spread of the virus among the research community and within local settlements and vulnerable Indigenous communities (Uryupova, 2021[23]). In some instances, the scale of response efforts has impacted the funding allocated to non-COVID research activities. In space and arctic research, for example, these challenges will translate into a 'gap' in longitudinal data collection and may impact researchers' ability to understand rapidly changing arctic conditions and develop accurate climate scenarios.[12]

There is concern as to whether these interruptions will have enduring implications regarding the science that will be required to respond to potential future crises and societal challenges, such as climate change. Consequently, as the COVID-19 pandemic response transitions to recovery, the scientific community and science policymakers and funders must take swift action to re-evaluate research agendas and reinstate support for those activities impacted by delays and reduced resources. It will also be important to augment established priority setting processes so that during future crises, there are mechanisms in place to ensure that adequate support is maintained for important research activities that lack direct relevance to the immediate crisis at hand.

Meta-Theme: Agile and strategic mobilisation of science capacity

Interventions for Resilience	Required Actions
1. Take a systemic and long-term approach to science system investments to improve their ability to prepare for and respond to crises and build resilience.	1.1. Establish and communicate consistent and long-term strategies and investments for science systems. It is important that interactions across institutions, disciplines, sectors, and geographies are considered to leverage synergies, avoid unnecessary duplication, and address gaps in existing capacity. 1.2. Evaluate the capacity of science systems to respond to severe stress to ensure that investments are made which strategically extend the limits, stability, and resilience of established capacities. 1.3. Improve connections between science systems and all socio-economic sectors to ensure that scientists can collect, access, and use relevant and timely data, develop research agendas with broad relevance across sectors, and to support the efficient uptake and implementation of research results and innovations.
2. Leverage and build on established capacities to improve the agility and adaptability of science systems when responding to crises.	2.1. Develop and maintain sufficient levels of specialised scientific, managerial, and administrative capacity in national science systems to respond effectively to crises. 2.2. Mitigate the long-term impacts of crisis response on human capacity by integrating HR considerations into strategies and foresight activities undertaken during crisis preparedness, response, and recovery. 2.3. Support and incentivise the uptake of novel innovations, such as digital technologies, by science systems, particularly where they will be key to improving operational resilience and supporting the ability of researchers to operate at the cutting edge of research.
3. Re-design science programming and funding processes, to facilitate the expedited and agile mobilisation of existing and new resources as required.	3.1. Improve the ability of policymakers and scientists to work together to flexibly set, reassess, and adjust priorities and funding allocations in response to changing needs and levels of urgency. 3.2. Accelerate the ability of institutions, teams, and individual scientists to access crisis-specific funds and pivot established projects and funding in response to emerging crises and challenges. 3.3. Incentivise and enable actors, institutes, and infrastructures to undertake or support activities outside of their limited mandates and establish novel priorities and initiatives as important new needs emerge. 3.4. During crises, ensure that adequate support is maintained for research that has no direct relevance to immediate crisis response efforts but may have unforeseen relevance for potential future crises and/or complex societal challenges. During recovery, the re-allocation of funding and resources may be necessary to ensure that critical advancements are not significantly delayed or prevented.

Section endnotes

[1]The German High-Tech Strategy (HTS) was first introduced in 2006, as a framework to co-ordinate federal science, technology, and innovation (STI) policies (EC-OECD, 2023[95]). In part, this has been achieved by the engagement of almost all German ministries. The pandemic has illustrated the importance of the HTS in the German context and the cultural shift it represents toward cross-government collaboration, future-focused government funding, and societal resilience. HTS has an advisory council to ensure that the strategy is adapted as needed. In response to the COVID-19 pandemic, the advisory council released, 'Seven guidelines for new growth', a set of recommendations that reflected on ways in which innovation policy could be used to overcome the crisis (Hightech Forum, 2021[112])..

[2] Despite efforts to introduce novel digital technologies, such as the transition to digital patient records and the broader digitalisation of hospitals, progress has been stymied in Germany due to incompatible and onerous software, standards, and administrative procedures (Furlong and Busvine, 2022[113]). Much of this difficulty stems from the decentralised nature of the healthcare system. The United States faced similar challenges during the pandemic response. An investigation by POLITICO (https://www.politico.com/news/2021/08/15/inside-americas-covid-data-gap-502565) revealed that despite general awareness many state health departments are limited by their use of outdated technologies, while little additional support was being provided federally (Banco, 2021[114]). As a result, rather than sending electronic records, laboratories in almost every state provided data through traditional channels, including faxes, email, and even regular mail.

[3] The joint statement of the Science Foundation Ireland (SFI), the Irish Research Council (IRC), and the Health Research Board (HRB) aimed to communicate the efforts of the agencies to understand the impacts of the pandemic on researchers and take appropriate mitigating measures in relation to deadlines, extensions, budget reallocations, and restrictions on research activities (https://www.sfi.ie/research-news/news/covid-19/). The agencies also held regular calls with national research and academic institutions to monitor impacts on the domestic research community.

[4] Many countries introduced targeted supports to mitigate the long-term impacts of COVID-19 on researchers. The New Zealand Ministry of Business Innovation and Employment launched a one-off initiative, the Science Whitinga Fellowship to provide $10 million to support 30 early career researchers as fellows in their chosen fields over 2 years. The award was intended to address reductions in opportunities for early career researchers and diversity targets were integrated into its design. Both the Wallonia-Brussels Federation and Flemish governments approved special funds to doctoral researchers and postdoctoral scientists whose research was impacted by the pandemic (Bebiroglu, 2022[116]).

[5] In Chinese Taipei, the National Health Command Centre has used an integrated information system to provide up-to-date guidance throughout the pandemic. Big Data, integrated from a variety of sources, was analysed to provide clinicians with alerts in real-time during clinical visits to support the detection of cases (Kornreich and Jin, 2020[117]). In Korea data collected in a standardised way through the universal healthcare system was critical to some aspects of the national pandemic response; for example, the COVID-19 International Collaborative Research Project, carried out valuable analyses, which informed mitigation policy, using time series healthcare use records for the entire population (Rho, 2021[118]).

[6] In South Africa, robust genomic sequencing infrastructure, including the Network for Genomic Surveillance (NGS-SA), the KwaZulu-Natal Research Innovation and Sequencing Platform (KRISP) and Center for Epidemic Response and Innovation (CERI), played a key role in detecting the Beta and Delta variants of SARS-CoV-2. Identification of the Beta variant allowed the government to introduce new legislation and public health guidelines within 2 days (Gatticchi and Ritchie, 2021[119]). Genomic sequencing has also contributed to the United States pandemic response, such as with the development of a new national genomic surveillance consortium, SARS-CoV-2 Sequencing for Public Health Emergency Response, Epidemiology, and Surveillance (SPHERES). The consortium co-ordinated large-scale rapid SARS-CoV-2 genomic sequencing across the country to support surveillance of variants, manage contact tracing, and advance related research (Thulin, 2021[120]). However, the pandemic has emphasised also the challenges posed by underfunded labs and disconnects between sequencing demands and capacity.

[7] Many countries leveraged both novel and established funding mechanisms to expedite the distribution of funding to projects targeted toward the COVID-19 pandemic. Agencies, including the Canadian Institutes of Health Research (Canadian 2019 Novel Coronavirus Rapid Research Funding Opportunity launched February 14, 2020), United Kingdom Research and Innovation (Coronavirus Research: Rapid Response Call launched February 4, 2020), the United States National Science Foundation (Rapid Response Research programme dedicated call in March of

2020), the French Agence Nationale de la Recherche (COVID-19 flash call launched in March 2020), and the Japan Science and Technology Agency (J-RAPID program call launched in April 2020), were able to leverage existing mechanisms to put out funding calls in the early stages of the pandemic. Funding agencies also adopted innovative approaches, such as the use of short videos by Science Foundation Ireland and the European Commission, to accelerate the pre-screening of projects.

[8] In the European Union, the Force Majeure clause was used in administration of Horizon 2020 programming to maximise flexibility of grant management guidelines. Bureaucracy was limited regarding the eligibility of costs, project duration and start dates, delays in the submission of deliverables and reporting, and reorientation of projects (European Commission, 2020[121]). In Portugal, the novel Research 4 COVID-19 programme was introduced to encourage individuals and research teams committed to established projects to pivot their efforts to address immediate needs of the National Health Service.

[9] Despite operating in a scientific field lacking direct relevance to the SARS-CoV-2 outbreak, the Italian National Institute for Nuclear Physics (INFN), introduced several internal mechanisms to facilitate the contribution of established capacity and expertise to response efforts (INFN, 2020[122]). Another illustrative example of pivoted operations is EU-OpenScreen–ERIC, a distributed, experimental, and informatics-based fundamental research infrastructure consortium targeted toward chemical biology and early drug discovery. The consortium's established cross-infrastructural workflows for chemical screening, structural biology, and data analytics were directly applicable for the work required to identify and evaluate candidate molecules for COVID-19 therapeutics (https://www.eu-openscreen.eu/covid-19/eu-openscreen-eric.html).

[10] Canada launched a Research Continuity Emergency Fund in May 2020 with CAD 450 million to provide wage support to universities and health research institutes and to fund extraordinary incremental costs related to the maintenance of essential research commitments. Similarly, in July 2020, EUR50 million was allocated by the Irish government to the Higher Education Authority to enable the extension of research that had been significantly disrupted by the pandemic.

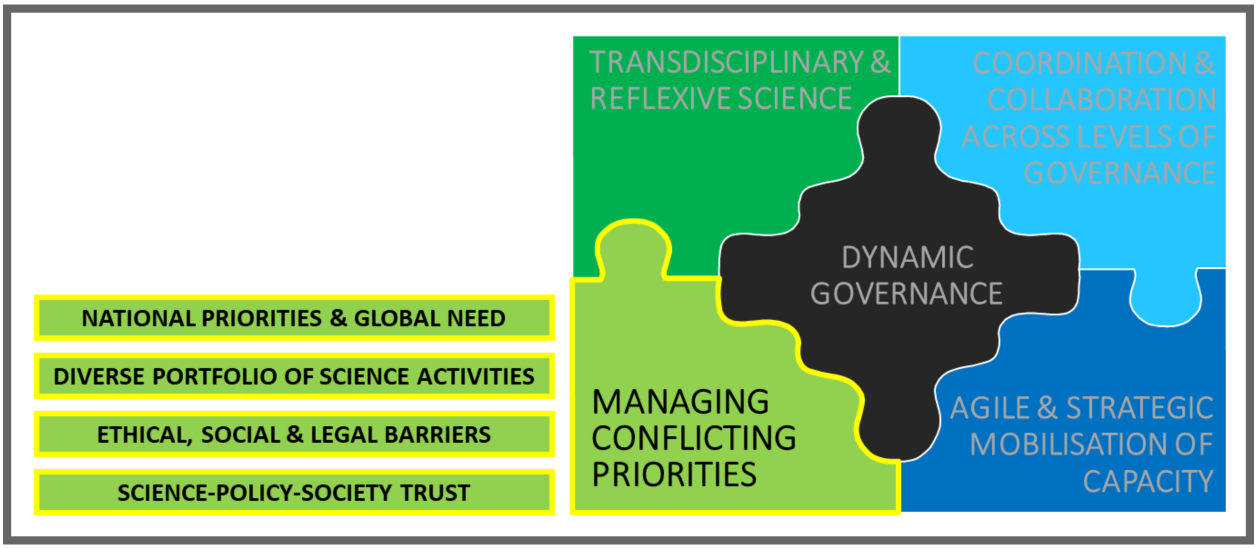
[11] All 30 members of the DEFEND consortium (https://defend2020.eu/about-us/) a Horizon 2020 project to control the spread of African swine fever and lumpy skin disease virus in Europe and neighboring countries, have been impacted by the pandemic. Some have shut down, others have been restricted to essential work, and many were required to repurpose resources to support the pandemic response (DEFEND, 2020[123]). The pandemic has also impacted funding commitments in other areas. A notable example is the 2019 commitment of the United Kingdom Government to double funding into dementia-related research (Inge, 2021[124]). A corresponding increase in funding has yet to materialise. Yet, at the peak of the COVID-19 outbreak, dementia fatalities were twice the normal number and in spring of 2021, dementia displaced COVID-19 as the primary cause of death in the United Kingdom. A recent survey also indicates that due to impacts of the pandemic on research activities, 1 in 5 dementia researchers may leave the field with 1 in 3 considering departure from research altogether (Alzheimer's Research UK, 2020[125]).

[12] After continuous work over 5 years, the international EastGRIP project (https://eastgrip.org/ was forced to suspend ice drilling in Greenland in 2020. The project aims to improve understanding of the role glacier ice streams play in rising sea levels. Continuity in sampling and data collection is important for analysing the effects of climate change on glaciers.

2 Managing conflicting priorities and interests in science

Different countries and actors from diverse scientific disciplines, sectors, and policy domains have conflicting priorities and interests in terms of scientific activities and outcomes. There is a need for fundamental, applied, and challenge-oriented research that has to be accommodated within the limited resources that science policymakers have to invest. Tensions and trade-offs must be understood and accommodated by researchers and science policymakers to ensure that science effectively contributes to crises preparedness, response and recovery.

Figure 3. Meta-theme: Managing conflicting priorities and corresponding interventions



Note: Overview of the interventions proposed for the meta-theme: Managing conflicting priorities (outlined in yellow).

Recognising and addressing tensions between national priorities and global need

Many aspects of the COVID-19 pandemic response illustrate the importance of having inclusive global capacity to prepare for and respond to an emerging crisis. The modern world is the most interconnected and interdependent it has ever been in terms of international travel, trade, and value chains. As such, no matter the policies implemented by countries to mitigate, contain, and curb the spread of the virus, the true end of the pandemic has only come into sight as focus has shifted more materially to supporting low and middle-income countries (LMICs) in their response efforts. LMICs often face disproportionately high burdens from infectious disease outbreaks, in addition to other complex societal challenges, such as environmental change (United Nations Publications, 2020[24]). At the same time, they also often lack sufficient and stable capacity to monitor and respond to these burdens. Efforts have been made over several decades to try to build this capacity and significant investments were made during the pandemic response, particularly in relation to data collection and stewardship.[1] Yet, for various reasons, the scale of these efforts has fallen short of what is needed. Going forward, it will be important for more affluent countries and donors to continue to support the development of scientific capacity in LMICs.

In the wake of the COVID-19 pandemic, there has been growing recognition that new approaches are needed to ensure the equitable representation of LMICs in the development of international science activities (ICRI, 2021[16]). For example, action is required to address the shortage of RIs in the Global South. There have been multiple calls to improve international vaccine security and the equitable distribution of medical countermeasures. Although these have been stated priorities throughout the pandemic, corresponding action has often been undermined by geopolitical and commercial interests, including exclusive advance-purchase agreements between pharmaceutical companies and developed countries (Gruszczynski and Wu, 2021[25]). Collaborative efforts, such as COVAX, have been criticised for approaches favouring one-dimensional criteria instead of considering context-specific factors like outbreak severity and healthcare system resilience (Asundi, O'Leary and Bhadelia, 2021[26]). While there have been partnerships forged directly between industry and LMIC-based research institutes, many have lacked the potential to create real, sustainable change as their primary focus has been on reacting to the immediate challenge rather than building lasting capacity.

The COVID-19 pandemic has emphasised the necessity of investing proactively in the development of STI capabilities in the Global South. National or regional scientific initiatives must leverage established foundational capacity, infrastructure, formal and informal institutions, and enabling framework conditions (Stewart, 2008[27]).[2] This is important to ensure their ability to prepare for and respond to crises and complex societal challenges at the domestic level, but also to ensure that LMICs are represented in, and benefit from, global science activities. The ability to make use of knowledge depends on access to that knowledge and also on the availability of absorptive capacities (von Hippel, 1994[28]) (Schot and Steinmueller, 2018[29]). Once a crisis hits, there is significant pressure on all countries to optimise domestic outcomes and those countries that are highly dependent on external scientific capacity are inevitably at a major disadvantage. In this context, emerging economies with relatively strong scientific capacity and international connections, such as South Africa, can provide an important bridge between North and South. Regional intergovernmental agencies also have a role to play in fostering networks within developing regions and bridging the build-up of capacity with the realisation of inclusive global science activities.

Over the first year of the pandemic, the global research response was significant. In this time, the COVID-19 Research Project Tracker (https://www.ukcdr.org.uk/covid-circle/covid-19-research-project-tracker/) documented the launch of over 10,500 projects in 142 countries, representing an investment of $4.7 billion by over 200 funders (COVID CIRCLE, 2021[30]). Whilst this data is not fully comprehensive, analysis clearly indicates that COVID-19 research involving LMICs was lacking, with limited regional co-ordination and funding thinly spread across a multitude of small-scale studies. Of the projects captured by the tracker, a small minority are multi-country collaborations (425) and an even smaller number involve at least one LMIC (267).

It is evident that greater co-ordination and collaboration is required across national governments and funders to ensure that in responding to a crisis, research investments have the greatest possible impact on the most critical global needs. Important efforts have been made by several international organisations, such as the WHO and the Global Research Collaboration for Infectious Disease Preparedness (GloPID-R), to bring experts together on a global scale to develop the international research agenda. However, translating the awareness generated by these activities into effective collaboration and co-ordination among funders, governments, and research institutes has proven to be more difficult in practice, in part, due to the conflicting priorities of different actors.

Learnings from COVID-19 indicate that impediments to the rapid distribution of research funding during a crisis can be compounded by the inclusion of LMIC partners (COVID CIRCLE, 2021[30]). These challenges have been most readily circumvented when funders were able to allocate funding through already established partnerships, and capacity. Many funders were challenged by a general lack of understanding of local capacity, needs, research requirements and priorities. Future action, such as GloPID-R's pilot of geographical hubs, will be required to provide better insight into local funding needs and initiatives. Mapping available capacity in LMICs can also support funders in developing future collaborations with greater precision.[3]

Supporting a portfolio of science activities that balances the pursuit of academic, societal, and commercial outcomes

The initial research response to the COVID-19 pandemic in most countries focused primarily on understanding the virus, its transmission, and finding effective medical interventions. Scientists were able to leverage and build on a wealth of knowledge from basic research, such as the advancement and application of mRNA technologies, as well as advanced understanding of coronaviruses from previous outbreaks.[4] The foundation provided by decades of past investment explains the unprecedented speed with which effective vaccines and diagnostics were developed. It demonstrates the necessity for science policy support to a diversity of research and technology areas over the long-term. While it is important that funding allocations to priority areas of research are significant enough to support a critical mass of activity, science policy must also cultivate resilience by balancing challenge-oriented initiatives with blue skies, discovery research for which the main aim is simply to advance human knowledge.

With specific regard to public health, the pandemic response has highlighted that more research is required to address non-biomedical aspects of outbreaks, such as public health and social measures (PHSMs), risk communication and behavioural insights, and long-term preparedness. Traditionally, these topics have not been high on research agendas because other areas, such as vaccine development, are often associated with greater incentives in the form of financial returns and national prestige. Science-based and future-focused priority setting mechanisms are needed to ensure that the most transformative opportunities are supported at a level that enables their advancement. One of the major justifications for government intervention in STI activities has been that industry stakeholders are not adequately incentivised to produce a desirable level of scientific knowledge under normal conditions (Nelson, 1959[31]) (Arrow, 1962[32]). More recent adoption of challenge-based programming recognises that, on top of this, governments also have a major role to play in directing the advancement of science towards the resolution of societal challenges (Schot and Steinmueller, 2018[29]).

Tensions inherent to science-industry and broader, transdisciplinary partnerships arise from the differing, and often conflicting priorities and circumstances of actors from different domains. Yet, these partnerships are critical to affecting the change within science systems (and society) required to respond more effectively to crises and complex societal challenges. This is true of the combinatorial effects that come from the co-ordinated use of funding, data, and other resources, but also from the combination of diverse knowledge and perspectives. (See ahead, the chapter on Transdisciplinary and Reflexive Science for insights from research collaborations that successfully engaged a diversity of stakeholders during the pandemic).

The COVID-19 pandemic catalysed an unprecedented level of altruism among many actors and enabled actions previously discounted as improbable. However, the transition from pandemic response to recovery has been marked by a reversion of many of these activities and a return to business as usual. While several calls for more enlightened approaches to IP management and licensing have emerged, there has been considerable pressure to maintain more traditional forms of monopolisation and commercial competition. For example, several pharmaceutical companies committed to not enforcing IP during the pandemic response to enable vaccine development in LMICs but it appears that it has opened the door for patent infringement by industry competitors, leading to disputes and litigation between rival companies (Robbins and Gross, 2022[33]).

Concerted global action is also required to prevent a similar reversion in the progress made to advance international Open Science agendas. The pandemic has been a driving force for open access to publications and open data. Around the world, many governments and funders have introduced policies mandating that results from relevant publicly funded research be made openly accessible. This has been complemented by the collaborative efforts of commercial publishers and public institutions to improve access to coronavirus-related research.[5] At the same time, experts have pointed to the limited nature of these concessions with many being conditional, partial and/or time-restricted, and have questioned the extent to which this progress will be sustained in the future (OECD, 2020[34]) (Lariviere, Shu and Sugimoto, 2020[35]). Tools to accelerate the communication of findings, such as preprint platforms and expedited peer review processes were also widely adopted; however, the pandemic has also emphasised the need for appropriate safeguards in the interpretation of preliminary scientific findings (Sarabipour et al., 2019[36]).[6]

Open access publications pose significant risk to the commercial viability of conventional publishing business models. There are also significant conflicts between Open Science principles and current academic incentive and evaluation structures. In academic settings, professional advancement and research funding often depend on the authorship of academic papers and their publication in prestigious periodicals (Grant, 2021[37]). The need for researchers to safeguard the novelty of their findings creates a perverse incentive to limit access prior to publication and to publish in high impact journals that are not open access. While peer review and publication in highly rated journals can provide verification and validation of scientific results, they can also delay and limit access to evidence of critical importance for crisis response. There has been progress in reimagining science evaluation and incentive frameworks over the past decade but more must be done in the future.[7]

The international science community and domestic science policymakers have important roles to play in developing and maintaining conditions that will minimise conflicting priorities. In this regard, it is important that progress is made proactively in a structural and systematic way. The need to ‘switch on’ open access measures or wait for a disruptive emergency to corral stakeholders into collective actions risks wasting valuable time in the early stages of a crisis (GloPID-R, 2019[38]). Rather, steps must be taken now to affect a shift in culture and foster resilience in science systems and society. Policymakers can build on what is already happening by adjusting conventional funding and evaluation processes to take account of changing objectives and important scientific contributions, beyond the narrow production of new knowledge, that are not currently valued (see the section on dynamic governance).

Identifying and managing ethical, legal, and social issues that impact research in crises

In terms of conflicting interests, the COVID-19 pandemic response provides a case study on how accelerating scientific advancement can, in some circumstances be impeded by rigid ethical guidelines and review procedures and a strong emphasis on individual rights and freedoms versus collective societal benefit. This tension limited the ability of researchers in some jurisdictions to introduce rigorous experimental evaluation of PHSMs.[8] Another area of the response characterised by ethical, legal, and social issues was the use of advanced digital technologies, such as geolocation and biometrics in contact tracing efforts. While different approaches have been adopted across countries for the collection and use of personal data, a number of international organisations have raised serious questions about the risks these technologies pose to human rights (Bentotahewa, Hewage and Williams, 2021[39]). Many East Asian economies were able to leverage learnings from previous crises and prioritised the engagement of the public in agreeing frameworks for the use of personal data. The result, particularly at the onset of the pandemic, was a swift and aggressive response that effectively coupled diagnostic testing and contact tracing and was relatively successful in minimising transmission.

European countries have been guided by the General Data Protection Regulation (GDPR) in the approaches they have adopted for the collection and use of personal data.[9] While the aim of the GDPR has been to harmonise data protection standards across the European Economic Area, the regulation delegates authority to member states in matters related to data stewardship for the public interest (Becker et al., 2020[40]). During a public health crisis, this can result in inconsistencies in the approaches taken by countries and impedes joint efforts. It is important that trade-offs between data openness and privacy in the context of crisis response are considered and integrated into regulations, ideally before a crisis takes place (OECD, 2020[17]).

Ethical, legal, and social issues associated with data extend across the whole data management life cycle. Management of clinical research data is governed in line with broadly accepted ethical and legal frameworks and accredited data repositories in many countries have well established mechanisms to ensure compliance. However, not all research domains were so well prepared at the onset of the crisis. Social and community-based surveys have been an important tool, allowing policymakers to target countermeasures and public communication to pressing public needs. Yet, in the absence of tested processes, ethical review procedures, and capacity, many countries have been slow to implement such surveys,.

While many of these issues are highlighted in the recent OECD Recommendation on Enhancing Access to and Sharing of Data (OECD, 2021[41]) others have become more apparent during the pandemic. The cross-cutting nature of the pandemic required the generation of interdisciplinary insights and the integration of data from different sources. Anonymised personal data has traditionally been considered secure; however, the scale and scope with which different datasets needed to be linked to generate valuable insights during the pandemic, emphasised that this practice can inadvertently expose personal identities (OECD, 2020[17]). It underscored that continuous action to ensure the evolution of data security and governance is imperative.[10] In a similar vein, the validation of scientific findings based on sensitive data posed unique challenges. Negative ramifications of events, such as the Surgisphere Scandal, illustrate the need for policymakers, funders, review boards, and scientists to work together to validate research results even, and especially, when sensitive data cannot be made openly accessible.[11]

Improving mutual trust at and beyond the science-policy-society interface

Ultimately, issues of trust were at the crux of many of the challenges for science during the pandemic. On average, the public's trust in scientific institutions has increased over the course of the pandemic. In the 2020 Wellcome Global Monitor, a survey of almost 120,000 people in 113 countries conducted from August 2020 to February 2021, more than three-quarters of respondent indicated 'a lot' or 'some' trust in science and scientists (Wellcome, 2021[42]). Conversely, in many regions, response efforts appear to have accentuated long-term trends of declining public trust in politicians and public institutions (OECD, 2022[43]). A lack of trust in responsible authorities has not only limited the willingness of individuals to adopt novel vaccines and adhere to evolving PHSMs but has also negatively impacted the ability of researchers to collect and use data to inform response efforts.[12] Foundational to the cultivation and maintenance of this trust are the relationships that different publics have with their governments and with science, but also the relationships between scientific institutions and government.

Some issues are structural in nature, stemming from historical legacies of distrust between public authorities and particular demographics, while others have been a function of the pandemic situation. As many countries contend with growing levels of polarisation, the pandemic has been exploited by opportunistic politicians as a means to advance their personal standing (Colman, 2021[44]). At the same time, scientists and science advice structures have not always been without fault in the politicisation of science.[13] Whilst uncertainty has characterised many aspects of the pandemic, the actions of a few 'rogue' scientists have underscored the importance of scientific integrity and rigour and the need to strengthen the distinction between academic freedom and personal freedom of expression. Going forward, it will be important to apply learnings from the pandemic to augment guidelines for good scientific practice. Scientific codes of conduct and notions of research integrity need to be extended to include activities related to scientific advice and public communication.

Measures to improve the transparency and accountability of the use of science to make policy decisions have signalled an important and necessary shift from conventional practices. Heightened interest and scrutiny of the public has cast a spotlight onto the scientific community, public officials and policymakers and required the clarification of roles, structures, and processes at the science-policy-society interface. Unfortunately, due to mis- and disinformation campaigns and subsequent polarisation and politicisation, researchers involved in public discourse have sometimes been subject to verbal and physical attacks (Wright, 2022[45]). Fallout from the practice adopted by many policymakers of 'blaming the science' for unpopular policy choices has critically impacted the ability of advisory structures to engage qualified scientific experts in some jurisdictions. Where this has been the case, action is needed to adjust incentives and limit or clearly define personal and professional risks and liabilities of science advisors. Defining and institutionalising responsibilities between policy and science actors can provide an important point of reference for improving the functionality of science advice structures and science-policy relationships. It can also improve the understanding and credibility of scientific processes among external stakeholders.

Another critical element that was often lacking in initial scientific communication efforts has been the openness and transparency with which assumptions and uncertainties were shared with the public. In the early days of the pandemic, many national governments and scientific experts were hesitant to admit the uncertainty of the evolving situation and the tentative nature of the evidence used to inform policy decisions. Failures to acknowledge and explain major changes to public health guidelines and PHSMs undermined the credibility of scientific and public institutions, increased polarisation, and, at times, even served to validate false or misleading information (OECD, 2020[46]). Insights from behavioural and communication science, indicate that in situations of extreme uncertainty, such as the COVID pandemic, public communication should be consistent, engage transparently with limitations in scientific knowledge to promote awareness of corresponding resolutions, and avoid shifting blame or downplaying citizen concerns (OECD, 2020[47]). These insights were often ignored during the pandemic, at least in the early stages of the response.

Many countries have struggled to integrate the needs, concerns, and lived experiences of diverse populations into communication campaigns. Successful campaigns have used a variety of mediums and messaging to communicate contextualised information in a way that resonated with different target audiences. It has been important for scientists and public officials to recognise and acknowledge the critical impact that context and values can have on the translation of science into policy decisions. Policy development is inherently normative and the prioritisation of certain values over others is a fundamental aspect of the process (OECD, 2015[48]). This was evidenced during the pandemic response by the evolution of PHSMs. It was common practice, in the early days of the response, for countries to implement stringent lockdown measures to limit infection rates. As the crisis progressed, many governments chose to relax PHSMs despite increasing levels of transmission (and even in the absence of high vaccine coverage). Alternative factors, such as economic recovery, were being given greater importance.

In a similar vein, the context and framing of scientific questions can have significant impact in terms of what data is collected, how it is analysed and used, and ultimately, the direction of resulting scientific advancement. Scientific knowledge develops within a value-rich context, which is often a function of the discipline under which the work has been undertaken (OECD, 2015[48]). Hence, it is important that the concerns integrated into scientific research and advice are representative of broader society and inclusive of the issues driving marginalisation and polarisation.[14] Conversely, it is also important to safeguard the independence, neutrality, and accountability of scientific processes and the use of resulting outputs to make policy decisions.

The pandemic has showcased the value of public engagement in the development, application, and uptake of science. For example, integrating insights from citizens has been critical with respect to the development of PHSMs that are targeted local contexts. Ensuring that these interventions reflected the specific challenges, needs, and experiences of individuals has been crucial to cultivating trust, buy-in, and ultimately, their widespread adoption. However, this issue is more complex than simply developing science engagement initiatives. It is widely recognised that people need specific skills to navigate, validate, and make sense of scientific information (Tan, 2022[49]) (OECD, 2020[47]) (OECD, 2020[46]). Scientific and digital literacy are crucial to empowering informed decision-making, fostering realistic perceptions of the scientific process, and enabling the navigation of increasingly prevalent misinformation. Targeted actions are needed to address historical deficiencies in this area and enhance the engagement of the public in scientific activities.[15]

At the same time, researchers also have a role to play in translating scientific concepts into terms and formats that are more accessible to the general public. The pandemic response has indicated that it may be necessary to explicitly expand the responsibilities of scientists beyond sharing information as it appears in the scientific literature.[16] However, responsible and effective scientific communication is not straightforward. In the latter days of the pandemic response, there has been increased recognition of the need for scientific communication to acknowledge uncertainty and adopt targeted and empathetic messaging. It is important that scientific communication that is targeted to public audiences is developed with the understanding that intended beneficiaries, potentially including scientists from other disciplines, will not have the same level of specialised knowledge (Nabi, 2021[50]). In this respect, the use of clear language, rather than technical jargon, is particularly important.

Cultivating and maintaining public trust in science, building on the interest and engagement that has grown over the course of the pandemic, will require that scientists proactively consider and monitor how their work may be interpreted or presented. Cycles of hype and disappointment can significantly impact public understanding, vulnerability to misinformation, and trust (Caulfield et al., 2021[51]). At the same time, mechanisms embedded in contemporary scientific processes, activities, and structures, from grant proposals to press releases and other interactions with the media, often incentivise the portrayal of scientific advancements in an overly positive light. Long-term investment to improve the public communication skills of researchers is one avenue science policymakers might pursue to address current shortcomings ((n.a.), 2020[52]). As raised in report 2 in this series, codes of conduct and guidelines for good scientific practice also need to be extended to incorporate the roles and responsibilities of scientists in communicating and engaging with the public.

Meta-Theme: Managing conflicting priorities

Interventions for Resilience	Required Actions
1. Recognise and address tensions between national priorities and global need regarding the development and deployment of scientific capacity.	1.1. Address deficiencies in the science capabilities of LMICs to ensure their ability to access and contribute to international science activities related to resilience and crisis preparedness and response. 1.2. Ensure the prioritisation of global public good(s) in addition to immediate national priorities through the active participation and representation of LMICs and related regional bodies in multilateral collaborations and international priority setting exercises. 1.3. International agencies, national governments and funders need to work more effectively together to co-ordinate investments and science activities in a way that maximises synergies and minimises duplication and gaps.
2. Maintain dedicated support for a diverse portfolio of science activities focused on solutions for socio-economic challenges as well as the advancement of science.	2.1. Support the development of diverse research portfolios and incentivise the advancement of critical areas that are conventionally challenged by underinvestment, such as public health and social measures. 2.2. Transform conventional funding and evaluation processes to simultaneously advance long-term discovery research and solutions-driven research and extend the priorities of scientific institutions beyond the production of publications and intellectual property. 2.3. Build on the advances made in Open Science, including enhanced access to data, publications, and other research materials, during the COVID-19 response. Embed successful emergency arrangements into routine practices as appropriate.
3. Systematically and proactively address ethical, legal, and social issues that impact on scientific studies and data collection.	3.1. Develop clear but flexible procedures for the collection, stewardship, and use of sensitive data during crises. These need to protect individual privacy, while expediting access to data for research across different disciplines. 3.2. Foster and leverage mutual trust and engagement between the public, scientists, and policymakers to improve the capacity of science and policy actors to deploy extraordinary measures for data collection and analysis during crisis response, whilst maintaining necessary safeguards to protect personal privacy and security.
4. Advance mutual understanding, improve trust and promote reflexive engagement between scientists, policymakers and the public.	4.1. Ensure that the development, communication, and translation of science into policy decisions is, transparent and accountable, and is done in a way that is sensitive to the needs and concerns of the target audience(s). 4.2. Bring together the experience and insights of different scientific disciplines and actors to develop effective approaches to managing mis- and dis- information, recognising that scientists themselves may, either deliberately or inadvertently, play a role in propagating such information. 4.3. Implement long-term initiatives to improve the scientific and digital literacy of policymakers, elected officials, and the public, with a particular focus placed on disadvantaged and underrepresented populations. 4.4. Incentivise scientists to engage with the public and improve their ability to communicate and explain processes, conclusions, and potential outcomes in plain language.

Section endnotes

[1]The Bill and Melinda Gates Foundation (BMGF) has contributed significantly to the development of scientific capacity in LMICs since its inception in 2000 and is one of the organisations operating in this space. One example is provided in report 2 regarding the development of the 2014 Ebola Emergency Operations Centre, an operational model which has been replicated across West Africa. In response to the pandemic, BMGF has introduced several new initiatives targeted to global pandemic preparedness and science in LMICs. The Global Immunology and Immune Sequencing for Epidemic Response (GIISER) program supports decentralised network of hubs, that aims to expand existing immunological research capacity in 8 countries across Africa, South America, and Asia. The intention is to ensure that local scientists have the capacity to rapidly detect SARS-CoV-2 variants and respond appropriately to address local needs.

[2] Following recommendations from the WHO International Vaccines Task Force in 2018. A mechanism was introduced in 2019 to support health research funders in identifying gaps in LMIC capacity and collaborating to address them. The ESSENCE on Health initiative has 3 workstreams: 1) development of core metrics to standardise assessment of national health research capacity; 2) strengthening World RePORT, an open database to map investments and partnerships of large health research funding agencies; and 3) convening of relevant stakeholders to enhance collaboration, review initiatives, and identify gaps (Kilmarx et al., 2020[136]).

[3] GloPID-R is currently in the process of developing 4 regional hubs in the Asia-Pacific region, the African continent, Latin America, and North America & Europe to support the co-ordination and improve the efficiency of research funding for infectious diseases. The intention of the regional hub strategy is to support inclusive and equitable global research preparedness and response by addressing the distorted distribution of research funding and enhancing regional ownership. The hubs will enable funders to better understand the local funding landscape, needs, and gaps of different regions. They will also be important to facilitating the targeted development of regional research networks, sustainable regional capacity for research and policy uptake, and regional research priority setting (GloPID-R, 2022[137]).

[4] Response efforts have recognised that the ability of science systems to respond to the pandemic have benefitted significantly from decades of investment into fundamental research. For example, mRNA-based COVID-19 vaccines have drawn on the contributions of hundreds of researchers over several decades. mRNA was first discovered in the 1960s and many advances in knowledge and technologies since then have contributed to the capacity of modern industry to harness it to rapidly develop novel vaccines (Dolgin, 2021[129]). mRNA vaccine platforms build on established vaccine technologies and have the potential to accelerate development and manufacturing processes without forfeiting safety (Pardi et al., 2018[130]).

[5] Many countries and funding agencies had open access policies in place prior to the pandemic and many others introduced or augmented policies in response to the pandemic. For example, the open access policy of the American National Institutes of Health (NIH) was initiated by Congress in 2004 and established in legislation in 2008 (Suber, 2008[128]). During the pandemic response, this precedent enabled the NIH- Biomed Central to leverage its established relationships with publishers, to enable open access to more than 185,000 scientific papers from the 1970s onwards. The Bill and Melinda Gates Foundation (BMGF) also has an established policy requiring that all the research it funds, with limited exceptions, is made publicly available at the time of publication (https://openaccess.gatesfoundation.org/open-access-policy/). This includes disclosure of a Data Availability Statement to provide the location of primary and meta-data and other tools required to understand and reproduce the results.

[6] A novel initiative, Outbreak Science Rapid PREreview aims to accelerate the review of outbreak-related preprints and support scientists in rapidly assessing their validity and value during public health crises. PREreview (Post, Read, & Engage with preprint reviews) is a digital infrastructure for crowdsourcing the peer review of preprints. It was initially founded in 2017 with the intent to make science more equitable, transparent, and collaborative and to address the slow, inefficient, and specialised nature of traditional peer review processes. In the United States, the MIT Press launched Rapid Reviews: COVID-19 (RR:C19), a journal designed to accelerate peer review of research related to the COVID-19 pandemic. The initiative uses artificial intelligence technologies to find potentially important preprint literature, delegate expert peer reviews, and make the results openly accessible (MIT Press, 2020[138]). The team behind RR:C19 is collaborating with COVIDScholar (https://covidscholar.org/) - a UC Berkely and Lawrence

Berkeley National Lab project - to support the rapid review of preprints through the development of new AI and machine learning tools.

[7] The Declaration of Research Assessment (DORA, https://sfdora.org/about-dora/) was developed in 2012 and has catalysed a global movement to reform research evaluation and assessment. In response to disruptions in scientific work in many fields during the pandemic, DORA called on institutions to ensure transparency regarding the evolution of evaluation frameworks and to redefine expectations for productivity where necessary.

[8] During the pandemic, there was a relative lack of research to expand the evidence-base related to public health and social measures (PHSMs). It was only in December 2021 that the results form a large randomised control trial in Bangladesh provided rigorous evidence on the effectiveness of face masks in preventing COVID-19 transmission (Abaluck et al., 2022[131]). (Peeples, 2021[132]) (additional detail is provided in report 2 in this series). Many countries lacked established mechanisms to support scientists in securing individual consent from study participants at the scale that would have been required to swiftly implement randomised control trials alongside the introduction of PHSMs in order to assess their efficacy. In response to this, Norway has established the Centre for Epidemic Interventions Research. The agency is intended to advance national PHSM research by proactively preparing for and implementing PHSM impact studies, supporting the translation of scientific evidence into policy decisions during health crises, and improving public health literacy.

[9] Several countries have attempted to introduce amendments to personal data legislation during the pandemic but have met challenges in getting them passed into law. In Germany, changes to the Infection Protection Law to give authorities the capacity to use technology to identify and trace potential cases received criticism from the Federal Privacy Commissioner (OECD, 2020[17]). Similarly, an amendment to the emergency law in France which proposed permission to use 'any measure' necessary to collect and process health and location data during a six month period was also rejected. On the other hand, success in leveraging, building on, or augmenting data privacy legislation has been achieved in some countries. Korean and Singaporean authorities were both able to use established mechanisms to collect personal data without individual consent if it was deemed imperative to the prevention and mitigation of infectious disease outbreaks. The Israeli government also introduced emergency measures to facilitate the use of surveillance technology to monitor mobile phones and track the movement of infected individuals.

[10] During the pandemic, the European Data Protection Board adopted new guidelines for the use and stewardship of health data for research purposes and the use of geolocation and alternative surveillance technologies in relation to the COVID-19 pandemic (OpenAIRE, 2020[139]). The intention of the guidelines was to provide clarity on several pressing legal questions, including the legal basis of processing data, adoption of adequate safeguards, and the rights of data subjects. The guidelines provide several provisions for the use of health data in scientific research and address the issue of consent in the context of existing national legislation and the international transfer of health data in the context of COVID-19. (https://edpb.europa.eu/sites/default/files/files/file1/edpb_guidelines_202003_healthdatascientificresearchcovid19_en.pdf)

[11] During the COVID-19 response, the accelerated release of scientific results and challenges with accelerated peer review led to the high-profile retraction of a number of significant studies. One of the most notorious studies, which was published in the prestigious medical journal, Lancet, came to be known as the 'Surgisphere Scandal'. In this case, anomalies were found following publication in the underlying data; however, the firm responsible for the clinical database used in the study refused to submit to an independent audit (Baker, Van Noorden and Maxmen, 2020[133]).

[12] Economic Impact and Elsevier launched a study to understand the perspectives of researchers regarding impacts of the pandemic on scientific research and its communication. Findings were published in a report in 2022, *Confidence in research: researchers in the spotlight*, and are based on the results of a literature review, a global survey of researchers, qualitative interviews, insights from an advisory board, and six regional roundtables (Economist Impact, 2022[140]). Key areas of concern and suggestions for action related to: the need to address misinformation; cultivating public trust and understanding; preparing researchers to take-on public-facing roles; and addressing inequality.

[13] Analysis has shown that social media tools, such as Twitter, provided a platform for actors to promote therapeutics, such as hydroxychloroquine, and other treatments with questionable efficacy for COVID-19 (Marcon and Caulfield, 2021[141]). Twitter provided a space for polarised political discussions, which were sometimes catalysed by bots reflecting geopolitical biases. Such exchanges often displaced or contaminated science-based exchanges. For example, collaborative efforts to either promote or critique the use of hydroxychloroquine could often be linked to partisan perceptions of the then United States political administration.

[14] Dedicated behavioural research used to inform South Africa's COVID-19 vaccination campaign indicated that youth, racial, disparity, low income, and government distrust were key contributors to vaccine hesitancy (Katoto et al., 2022[134]). Resulting recommendations included fostering collaboration between health and government agencies, using credible and dialogue-based communication campaigns, engaging directly with all individual demographics in accordance with type and severity of vaccine hesitancy, and investing in health literacy tailored to context-specific issues, including economic and racial disparity.

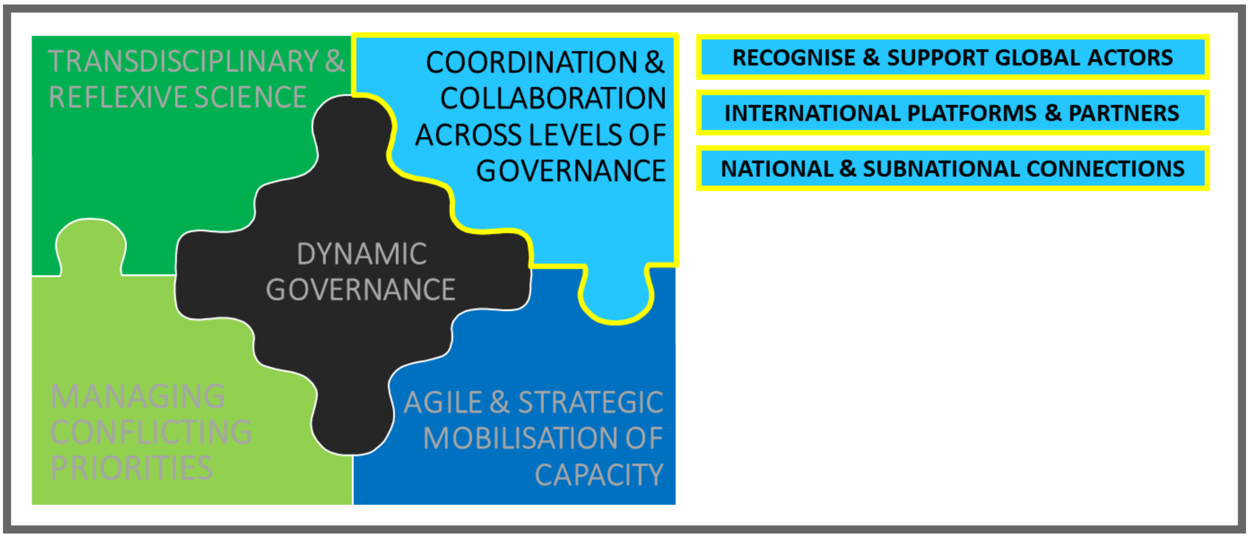
[15] In June 2020, the Singapore Smart Nation & Digital Government Office launched a technology literacy initiative, #SmartNationTogether (https://together.smartnation.gov.sg/about-snt/). It was intended to engage and support the public in developing important skills, knowledge, and perspectives to use technology to overcome the disruption posed by the COVID-19 pandemic (OPSI, 2020[142]). The initiative is a collaboration between the government and a network of community and private sector volunteers and since its inception, has introduced more than 70 programmes and engaged more than 6,000 participants. Online programmes are curated for different target audiences, including children, youth, young parents, working adults, and seniors.

[16] During the pandemic, the Dutch Research Agenda, allocated funding to a variety of innovative science communication initiatives targeted to improving the connection between science and society and making science more accessible to the public (Dutch Research Council, 2022[143]). There has been a focus on COVID-19 in these initiatives, but research activities have gone beyond this, also focusing on subjects such as climate change and youth participation. In conjunction with this stream of funding, the Dutch Research Council (NWO) has also partnered with the Impactlab of Leiden University and Utrecht University to develop tools for scientists to measure the impact of science communication efforts. A variety of long-term science communication and public engagement efforts have also been expanded or newly introduced in other countries as a result of the pandemic (see report 2 in this series).

3 Co-ordination and collaboration across levels of governance

Complex and cascading crises and societal challenges are often global in nature and effective response exceeds the capabilities of any single country. There is a need for co-ordination, co-operation, and collaboration between different actors at multiple scales of governance. Mandated international bodies play an important role in guiding co-ordination and collaboration across borders and governance levels. Collaborative platforms, infrastructures, and programming mechanisms can also make important contributions to the international, regional, and/or domestic harmonisation and integration of research activities.

Figure 4. Meta-theme: Co-ordination and collaboration across levels of governance and corresponding interventions



Note: Overview of the interventions proposed for the meta-theme: Co-ordination and collaboration across levels of governance (outlined in yellow).

Supporting and recognising efforts of international agencies to foster co-ordination, alignment, and collaboration

The COVID-19 pandemic called for international action, co-ordination, and collaboration to enable all countries to respond effectively. Global organisations and collaborative platforms have provided important leadership in this respect. Mandated organisations, such as the World Health Organisation (WHO), played a key role in guiding the development of research priorities across national borders. Global response efforts also benefitted significantly from guidance and initiatives organised by established co-ordination structures and platforms, such as GloPID-R and the WHO International Clinical Trial Registry platform.[1] In some instances, the pandemic has catalysed the creation of novel international collaborations, such as the International COVID-19 Data Alliance (ICODA), International Readiness for Preventing Infectious Viral Disease (INTREPID), and the Coronavirus Immunotherapy Consortium (CoVIC). Some of these platforms for collaboration may persist over the long-term, while others are likely to be dismantled or put on pause following the conclusion of response efforts.[2]

Measured against responses to previous public health crises, the levels of international co-ordination and collaboration that were achieved during the COVID-19 response have been unprecedented; however, significant obstacles to cross-border co-operation have persisted. In many respects, national governments have ended up competing instead of co-operating, a trend which has, as discussed earlier, disproportionately impacted LMICs. Challenges posed by cultural differences and conflicting interests, ranging from national security concerns to political, economic, and commercial priorities have constrained co-operation across borders and impacted the willingness of countries to accept and recognise the WHO as a legitimate global authority on public health (Hassan et al., 2021[53]).

International agencies, including the WHO, have faced a growing global trend toward nationalism, which has been accelerated, in some respects, by the pandemic response.[3] In the midst of the COVID-19 pandemic, geopolitical tensions resulted in the termination of a sizeable percentage of the WHO's funding from the agency's largest donor (KFF, 2022[54]). Contributions from the United States represent roughly 15% of the WHO budget and 23% of its budget for health emergency response. The decision has since been reversed with the election of a new United States administration. Subsequent steps have also been taken, or are being explored, to address structural challenges, such as inflexible funding processes, bureaucratic governance, and limited core funding that limit the WHO's efficacy. In the wake of COVID-19, it will be important for countries to continue to recognise the global benefits that result from international collaboration and deflect short-sighted and reactionary compulsions to reverse global co-operation (OECD, 2020[10]). Instead, co-ordinated and systems-based efforts to foster global resilience are required.

Prioritising the development and maintenance of inclusive multilateral collaborations

As the pandemic comes to an end, it will be important to continue to foster regional leadership, with particular focus placed on investing in and enabling action in developing regions. Countries with similar contexts or challenges stand to benefit from efforts to combine resources and co-ordinate activities around common research priorities. This happened, to some extent during the COVID-19 pandemic response, most notably in Europe, which was able to leverage longstanding efforts to build synergies and collaboration in the European Research Area. European initiatives are now being implemented to address some of the shortcomings identified during the pandemic response. These include the newly created Health Emergency Preparedness and Response Authority (HERA) of the European Union, which is mandated to centralise regional governance of crisis preparedness and response and co-ordinate the development of associated research and clinical trials (European Commission, 2021[55]). Important efforts to catalyse regional co-ordination and co-operation are also being made in other areas, including Africa and South-East Asia (see the section on conflicting priorities for additional details on some of these initiatives).

At the international scale, previously established and novel collaborations contributed significantly to the response to the COVID-19 pandemic.[4] At the same time, the speed of the pandemic's evolution and the disruptive scale of its impact brought weaknesses of global co-operation to the fore and emphasised the importance of strengthening underlying partnerships. International collaborations have been impacted by structural challenges, such as limitations in the use of national research funding for international activities, but also by issues inherent to crisis response. The expedited and continuous evolution of national research priorities has challenged co-ordination across borders, which has led to the significant duplication of research activities in some areas, as well as fragmented results, and a relative lack of rigorous studies in other important areas, such as PHSMs.

On a more granular level, where synchronised international initiatives were developed, such as with the Solidarity therapeutic trial initiative or the Discovery antiviral clinical trial, these often struggled to recruit an adequate number of participants to generate robust scientific results. This is partly explained by competition for enrolment due to the sheer number of other ongoing COVID-related clinical studies (Pearson, 2021[56]) (Seidler, 2021[57]).[5] A number of international clinical trials also faced complications and delays due to disjointed regulatory requirements and protocols across participating countries. These challenges were not new and some of them might have been resolved had appropriate action been taken by national governments prior to the pandemic (OECD, 2020[58]).[6] The RECOVERY trial, which rigorously tested a number of therapeutic agents for COVID-19, using a novel and flexible trial design that could accommodate different jurisdictional requirements, is a good example of what can be achieved when clinical centres in different countries collaborate.

With regards to PHSMs and the broader socio-economic dimensions of the pandemic response, international co-ordination has, until recently, been largely absent from research efforts (WHO, 2022[59]). While there have been striking commonalities across countries in terms of the overall impacts of the pandemic and the use of countermeasures and policy interventions, there has been a significant lack of action or appetite from national policymakers and scientists to share information on how national response efforts are evolving. The result has been a patchwork of policy with limited co-ordination or collaboration across countries and a missed opportunity to leverage joint research capacity, knowledge, and resources (Wang and Mao, 2021[60]). Addressing ethical, social, and legal issues and improving the understanding and application of PHSMs, will require science and policy communities to think and operate simultaneously in global collaborations before, during, and after emergencies.

On a structural level, barriers to broad and inclusive international collaborations are often compounded by the requirement for significant, sustained, and flexible funding commitments from countries. This precondition has been reduced, to a certain extent, by the introduction of digital infrastructures and tools, which can improve agility and overcome constraints posed by physical mobility requirements. Digital technologies were invaluable during the pandemic in enabling collaborators to communicate changing priorities, expectations, and concerns as the pandemic progressed. Nevertheless, there is still significant opportunity and need to advance global co-operation through the development of multilateral partnerships, international research infrastructures, and other means. As demonstrated by the COVID-19 Research Project Tracker discussed in section 2, this is particularly true in relation to the engagement of LMICs in international collaborations. Overall, a lack of effective international co-ordination between research funders, with scarce funding being distributed to many collaborative small-scale studies, has limited the impact of international research collaboration during the pandemic (COVID CIRCLE, 2021[30]). This is notwithstanding that many areas of research are inherently international and much of the scientific evidence produced during the pandemic was the result of bottom-up co-operation between researchers in different (mainly rich) countries.

To date, efforts to engineer cross-border or international initiatives have often been challenged by the need to engage and attain agreement among funders with heterogeneous and diverse priorities and diverse financial and scientific resources (ICRI, 2021[16]). This is particularly true regarding structural investments, such as international research infrastructures, that require funding to flow across borders. Going forward, innovative funding hybrids, combining the resources of governments, industry, philanthropic organisations, and, in the case of LMICs, official development assistance, might provide mechanisms to scale up investment in much-needed international science activities. Moving beyond current ways of doing things will be necessary to respond more effectively to forthcoming health emergencies and to address large-scale and complex global challenges (see the chapter on dynamic and system-oriented governance).

Taking action to co-ordinate, align, and connect science programming and initiatives at different levels of domestic governance

In most OECD countries, STI governance is distributed across multiple ministries and agencies, which have different priorities and requirements for research (OECD, 2012[61]). Within national and subnational science systems, the growing number and diversity of research infrastructures and institutions, while important in terms of addressing a variety of interdependent needs, has also increased complexity. In addition, sub-national regions or municipalities, particularly in federalist nations, often have their own scientific capacity and may even be the primary authority on the functioning of certain sectors, such as public healthcare. With regards to the COVID-19 response, co-ordination across levels of government was critical to national response efforts across all aspects of science, from the development of studies and scientific advice to its translation into policy decisions and subsequent public communication efforts. However, in many instances, the need for rapid action across many sectors exacerbated existing structural siloes within and between levels of government.

The pandemic has demonstrated that the co-ordination of local and national science activities must extend beyond the efficient deployment of resources. Cross-agency and cross-government co-operation has been important to mitigate the development of narrowly defined and overlapping funding calls, and fragmented research activities. In some countries, relevant actors have taken the initiative to map ongoing and planned COVID-19 research projects to improve co-ordination and reduce duplication.[7] In other contexts, government committees have been established to manage the alignment of research activities more actively.[8] Vertical co-ordination and co-operation between national and subnational policymakers has also been important. Some federalist countries were well positioned to leverage existing mechanisms designed to facilitate collaboration between national and subnational governments.[9] Local dynamics have contributed to the severity of the crisis and particular places and demographics have experienced disproportionate impacts for a variety of reasons, including disparities in social determinants of health and the quantity and quality of healthcare services (OECD, 2021[62]). An effective response has required national policymakers to engage with local actors and use related insights to target PHSMs and medical countermeasures to territorial needs.

The OECD has put forward several recommendations regarding multi-level governance in crises, including clarifying roles and responsibilities, improving communication, and sharing evidence and data to address place-based impacts (OECD, 2021[62]) (OECD, 2017[63]). National leadership is critical in terms of co-ordinating the implementation of research priorities and the uptake of resulting insights and innovation. At the level of research funding, some governments were able to leverage horizontal governance bodies that were already established. Where they existed and had the necessary authority, these structures were positioned well to facilitate the development of joint research programmes and the concentration of resources towards shared priorities.

Meta-Theme: Co-ordination and collaboration across levels of governance

Interventions for Resilience	Required Actions
1. National governments must recognise and support the efforts of international agencies to foster co-ordination, alignment, and collaboration of research, to improve global preparedness and resilience.	1.1. Foster and maintain awareness of, and support for, relevant organisations, at the international level. In the light of COVID, it is critical to identify and address gaps or tensions between established mandates, capabilities, and resources, and nascent or forthcoming risks. 1.2. Leverage and build on established channels for international engagement to expedite co-ordination, co-operation, and knowledge sharing. Targeted action will be especially important to address deficiencies in crisis preparedness and response that became apparent during the COVID-19 pandemic (e.g., scientific advisory processes, public health and social measures, and the co-ordination of research activities). 1.3. Incentivise and improve engagement and co-ordination between different intergovernmental bodies and agencies to limit duplication, maximise synergies, and leverage complementary networks, resources, and capacities.
2. Prioritise the development and maintenance of multilateral collaborations and international platforms to improve the visibility, alignment, and co-ordination of national science activities and assets.	2.1. Invest in developing and maintaining international science activities, including bi- or multilateral collaborations, co-funded research infrastructures or programmes, and other initiatives targeted to bringing scientists together across borders. 2.2. Promote, or, where necessary, mandate, the use of universal best practices or standards for clinical and other studies/trials to ensure ethical and scientific rigour and facilitate multi-centre studies and meta-analyses. 2.3. Support the development and co-ordination of national and international platforms and repositories for the registration, harmonisation, and/or federation of research studies, including clinical trials.
3. Co-ordinate, align, and connect science programming across national and subnational levels of governance.	3.1. Ensure mutual clarity between national and sub-national science policy actors regarding the division of responsibilities for crisis preparedness and response, as well as the complementary capabilities and resources that each actor provides. 3.2. Invest in developing and maintaining open communication and partnerships between national and sub-national actors to enable the swift, co-ordinated, and synergistic mobilisation of scientific resources at multiple levels of governance. 3.3. Mitigate territorial disparities and deficiencies by facilitating connections and incentivising collaboration between subnational policymakers, institutions, and researchers with complementary resources or comparable conditions.

Section endnotes

[1] The WHO's International Clinical Trials Registry Platform (ICTRP, https://www.who.int/clinical-trials-registry-platform) is a cloud-based platform to improve the visibility and accessibility of research to those involved in healthcare decision-making. It aims to improve the transparency, validity, and value of the scientific evidence base and does so, in part, by aggregating studies from 17 primary registries and ClinicalTrials.gov. In response to the pandemic, the platform enabled a one-click search for COVID-19-related studies (Veryard, 2020[144]).

[2] Various previously established and new international initiatives contributed to the global response to the COVID-19 pandemic and many are referenced throughout the first two reports in the Mobilising Science project series. The INTREPID (International Readiness for Preventing Infectious Viral Disease) Alliance was formed prior to the pandemic to facilitate collaboration between pharmaceutical companies and non-profit research institutes on the development of oral therapeutics for emerging viral agents with pandemic potential (https://www.intrepidalliance.org/). On the other hand, the Coronavirus Immunotherapy Consortium (CoVIC, https://covic.lji.org/) and the international COVID-19 Data Alliance (ICODA, https://icoda-research.org/) are both targeted specifically to coronaviruses. CoVIC was created by the COVID-19 Therapeutics Accelerator to streamline research for anti-body based COVID-19 therapeutics, while ICODA was created by Health Data Research UK to overcome challenges associated with accessing and using health data during the pandemic response. The ICODA programme was completed in October 2022.

[3] Case studies on the activities of international agencies, such as the WHO, GloPID-R, CEPI, GISAID, and GAVI have been included in the corresponding sections of reports 1 and 2 in this series.

[4] There were a number of established international or multilateral research platforms that were leveraged to introduce COVID-specific multilateral funding calls during the pandemic. Several related programmes were supported by Eureka, which was largely a European Union initiative when it was created in 1985 but has since expanded from 18 to 47 countries, many of which are outside Europe (https://www.eurekanetwork.org/) . Specific to the South East Asian region, the e-Asia Joint Research Program (e-ASIA JRP, https://www.the-easia.org/jrp/), which was inaugurated in 2012, introduced an urgent joint call for research on medical and non-medical countermeasures for COVID-19. Individual countries also launched new funding calls targeted to multinational co-operation. In Korea, the National Research Foundation announced a Rapid Call for International Joint Research Against the Coronavirus in May of 2020. The United States National Science Foundation also issued a call for research to better understand the impacts and scope of the impact of the pandemic on international collaboration (National Science Foundation, 2020[145]).

[5] There have been a variety of efforts to develop international or cross-border clinical trial platforms to co-ordinate the advancement of research on vaccines and therapeutics for the SARS-CoV-2 virus. For example, The RECOVERY (randomised evaluation of COVID-19 therapy) trial is a University of Oxford-run international clinical trial aiming to identify and evaluate potential treatments for hospitalised cases (https://www.recoverytrial.net/). REMAP-CAP (A randomised, embedded, multi-factorial, adaptive platform trial for community-acquired pneumonia) is a global platform of experts, institutions, and research networks with participation from over 300 sites across 25 countries (https://www.remapcap.org/). It uses a flexible and innovative trial design to simultaneously assess the efficacy of multiple interventions for community-acquired pneumonia. VACCELERATE is a pan-European network that was developed to co-ordinate and accelerate the second and third phases of COVID-19 vaccine trials (https://vaccelerate.eu/) . Despite these efforts, more than 2,900 COVID-19-related clinical trials had been registered by May 2021. As a result, many of these lacked a robust sample size and were unable to develop statistically significant research results (Pearson, 2021[56]) (Seidler, 2021[57]).

[6] The OECD's 2012 Recommendation on the Governance of Clinical Trials outlines challenges to the harmonisation and standardisation of international clinical trials. It advocates for consistent and risk-based clinical trial regulations and the standardisation of requirements across countries (OECD, 2013[146]). However, challenges experienced

during the pandemic response in co-ordinating the development of global clinical trials indicate that efforts to harmonise clinical trial requirements have not been fully effective.

[7] As part of its Rapid Response Research program targeted to COVID-19, the United States National Science Foundation supported a project from Columbia University to develop a COVID Information Commons (CIC). USD 200,000 was awarded for creation of a website that would enable researchers, policy-makers, and other decision-makers from academia, industry, and the non-profit sector to make use of each other's findings and concentrate on advancing research with the greatest potential to mitigate broad impacts of the pandemic on society (National Science Foundation, 2023[147]). Information science methodologies were used to make connections across distinct projects and facilitate collaborations. As of September 2022, the CIC community included more than 2,300 individuals from roughly 650 organisations across various sectors in the United States and 25 other countries.

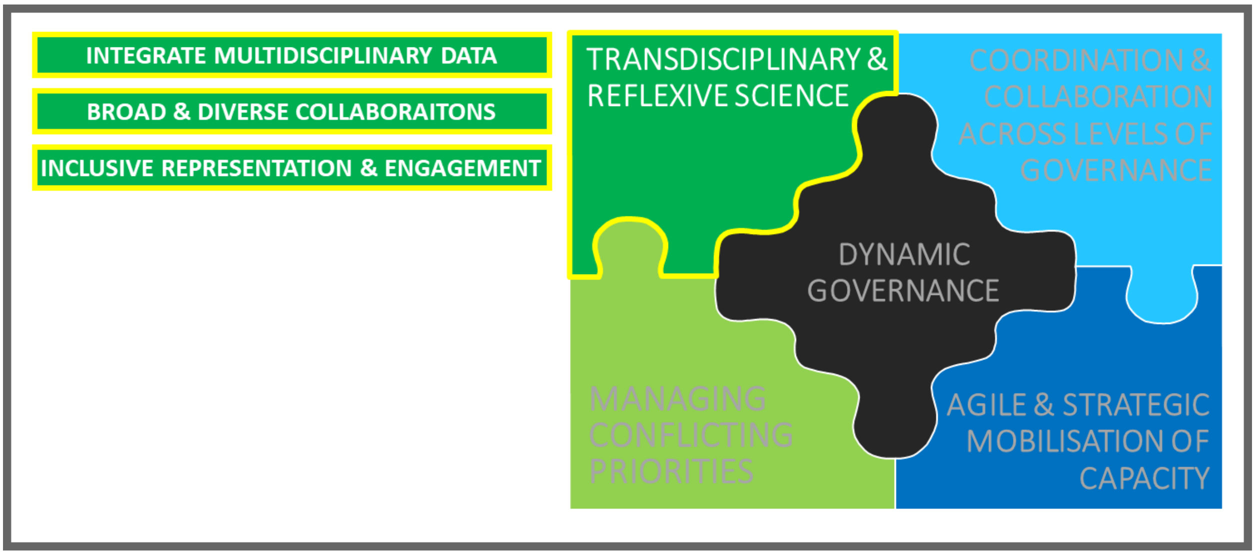
[8] In South Africa, a new inter-ministerial sub-committee was developed to co-ordinate a national research framework on COVID-19 (EC-OECD, 2023[95]). The committee brings together representatives from several national organisations, including the South African Health Products Regulatory Authority (SAHPRA), South African Medical Research Council (SAMRC), National Research Foundation, National Institute for Communicable Diseases (NICD), and the University of Cape Town. Its aim has been to support and co-ordinate targeted research, reprioritise existing research strategies, and create enabling ethical and regulatory conditions to facilitate relevant research.

[9] In Canada, policymakers were able to use the existing federal-provincial-territorial (F/P/T) Public Health Response Plan for Biological Events as a framework for the governance of collaboration between national and subnational actors during the pandemic response. The structure includes parameters for the development of several bodies, including three distinct advisory committees related to special, technical, and logistics-related issues and a Public Health Network Communications group (Public Health Agency of Canada, 2022[148]). Provinces and territories were responsible for adapting broad recommendations and other guidance products developed through these forums to their own jurisdictions. Another federalist country, Australia, was also able to leverage established structures. The Australian Partnership for Preparedness Research on Infectious Disease Emergencies (APPRISE, https://www.apprise.org.au/) was created in 2016 as a Centre of Research Excellence to improve the country's capacity to develop and utilise research to prepare, respond, and recover from infectious diseases. It is a national network of experts, institutions, and research networks from various aspects of outbreak response, such as clinical, laboratory, public health, and ethics research.

4 Transdisciplinary and reflexive science

Mobilising, integrating, and contextualising expertise, data, and knowledge from diverse scientific disciplines, sectors, and policy domains is necessary to address complex crises. However, the synthesis of multidisciplinary data into context-specific knowledge will require the advancement of global Open Science agendas and wide adoption of FAIR data principles, as well as specialised skills and new methodologies. Innovative business and funding models are also needed to incentivise inclusive partnerships. Insights from academia, government, industry civil society, and underrepresented populations are all critical to the development of solutions that are aligned with context-specific needs and challenges.

Figure 5. Meta-theme: Transdisciplinary and reflexive science and corresponding interventions



Note: An overview of the interventions proposed for the meta-theme: Transdisciplinary and reflexive science (outlined in yellow).

Collecting and synthesising multivariate and multidisciplinary data and insights to generate transdisciplinary knowledge

The integration of data and information from a wide breadth of disciplines and knowledge domains will be increasingly important to foster resilience in the face of escalating crises and complex challenges. The pandemic response has illustrated the value of Open Data and Open Science strategies, particularly with regards to the findability and accessibility of scientific information and data. Researchers responding to COVID-19 have benefitted from access to diverse data sources with unprecedented speed and granularity in comparison to other public health crises (Stoto et al., 2022[64]). The application of digital technologies, such as natural language processing and machine learning have been important in enabling and accelerating the large-scale analysis of information from various scientific disciplines and other origins, such as social media, and has enabled scientists keep abreast of advances in a rapidly evolving situation.[1] At the same time, many of the extraordinary actions taken in making scientific data and information accessible have been narrowly targeted to the pandemic and may be reversed following its conclusion (See chapter 2: conflicting priorities).

Constraints on the accessibility, interoperability, and reusability of data posed challenges for the development of domestic response efforts and the ability of researchers and policymakers to understand the local situation in the broader context of a cascading global crisis (OECD, 2020[34]). One of the aspects of the response where this has been notably consequential has been public communication and engagement efforts, where the quantity of available data, methodological inconsistencies, and lack of transparency concerning data quality and completeness have had serious implications for public trust. In some contexts, problems have been compounded further by the tendency for scientists and science policymakers to downplay, dismiss, and/or fail to appropriately address the uncertainty of scientific evidence (OECD, 2020[65]).

The urgency and complexity of the pandemic has magnified longstanding challenges limiting the interoperability and reusability of data, such as the use of different methodologies for data collection, documentation, and dissemination in different jurisdictions. In this respect, recent technological advancements and new tools have improved connectivity between data developers and prospective users and been key to ensuring that data are reused in alignment with the context in which they were developed.[2] In certain disciplines, universal data standards have been developed and widely adopted; however, uniform practices are still lacking in many fields. In this respect, individual and networked data repositories, digital platforms, and research infrastructures have been critical to facilitating the visibility, connectivity, and use of data during the COVID-19 response.[3] Prior investment of resources and time in building technical and social infrastructure has been an important factor in determining the preparedness of different scientific fields and their ability to respond and adapt to different needs as the pandemic has evolved. Unfortunately, the development of FAIR data sharing practices and infrastructures has been lagging in certain scientific areas, including social sciences.

Transdisciplinary research involves the co-design of research and co-production of knowledge between different scientific disciplines and non-academic stakeholder communities (OECD, 2020[66]). Unlike other forms of cross-disciplinary collaboration, such as multi-disciplinarity and inter-disciplinarity, the goal of transdisciplinary research is to transcend disciplinary and sectoral boundaries and generate knowledge beyond the boundaries of all contributing domains (Nicolescu, 2014[67]). This is often necessary to comprehensively address complex real-world challenges, such as many of those presented by the COVID-19 pandemic. Because transdisciplinary research generally requires participants to manage tensions between different scientific disciplines and stakeholders, as well as between scientific excellence, societal impact, the ethics of engagement, and other factors, reflexivity is essential to its success (Sellberg et al., 2021[68]).

With the COVID-19 pandemic, deconstruction of the evolving situation into underlying, interrelated elements was important to support the translation of information into actionable knowledge (OECD, 2012[69]) (OECD, 2018[21]). This practice of sense-making has also allowed experts to systematically reflect on the known, unknown, assumed, and unprecedented aspects of the situation. Drawing on expertise from a diversity of scientific fields and knowledge domains is key to protecting against one-dimensional framings and maintaining a holistic systems perspective. Overly simplistic situation analyses are more likely to arise in times of crisis, when researchers and policymakers must act with urgency and with limited preparedness (Benessia et al., 2012[70]). These, in turn, often lead to the development of 'silver bullet' solutions that target part of the problem but neglect other important aspects. Complex crises require researchers to have a mindset and culture that encourages reflexivity: an openness to reflect critically and adapt one's own positions and goals, to bridge and integrate information from a diversity of sources and moderate conflict, to deal with uncertainty through adaptation, and to test novel practices in pursuit of iterative improvement (Lindner, 2016[71]). This is not the normal modus operandi for many researchers and, whilst there are tried and tested methodologies to promote such transdisciplinary approaches these need to be more widely promoted and adopted across the science community.

Leveraging established and novel collaborations to integrate diverse insights

Addressing crises and complex challenges in the context of increasingly connected and interdependent societies will require scientific insights and innovations from a diverse range of actors, working together. This will require new modes of partnerships between a broader collection of contributors than has been traditionally prioritised. Collation and synthesis of inputs from across scientific disciplines and sectors is important to ensure that scientific activities and research agendas reflect a broad set of values and commitments and are based on a comprehensive understanding of the crisis situation as it affects different sectors of societies. Conversely, response efforts made in the early days of the pandemic tended towards myopia in that they were based mainly on inputs from only a handful of disciplines (OECD, 2021[72]). It is possible that this concentrated focus has contributed to the unprecedented speed at which new vaccines were developed. However, it has also been recognised that vaccines are one of many tools required to respond to a public health crisis and are a small, albeit important, piece of the overall puzzle (WHO, 2020[73]).

Interdependencies between the natural, social, political, economic, and technological aspects of a crisis require insights from the social sciences and community-based organisations to ensure that policy and countermeasures are aligned with the local context.[4] The significance of these insights became apparent as policy-makers and researchers struggled in their absence to implement PHSMs or develop effective vaccination campaigns (OECD, 2021[74]) (OECD, 2021[18]). Many countries have since taken action to address deficiencies; however, early mistakes have had repercussions throughout the pandemic response. This is a symptom of the siloed and specialised nature of many science systems and the persistence of embedded views and biases about the role (or lack thereof) of certain disciplines or knowledge domains in particular activities, such as scientific advice (Colman et al., 2021[75]). Counter to what is needed to address complex challenges, such biases encourage a narrow view of scientific knowledge and its real-world application.

In responding to the COVID-19 pandemic, it was important for countries to be able to leverage established partnerships and supporting mechanisms, such as digital platforms and other intermediaries, to accelerate the formation and functioning of collaborations involving a large diversity of actors. Research infrastructures (RIs), in particular, have the potential to play a significant role as sites of collaboration and focal points for the development and diffusion of pioneering research and data. They can provide a forum for the negotiation of conflicting priorities and aligning the expectations of disparate partners. There are numerous examples of where RIs acted as catalysts in the development and operation of large-scale research consortia and/or industry partnerships during the pandemic. The pandemic has also highlighted the value of mechanisms and processes that connect and streamline the use of different infrastructures for specific functions, such as drug repurposing[5].

During the pandemic response, digital technologies have been instrumental in connecting partners and accelerating the development of robust social capital. These technologies have enabled broad engagement within and beyond the science community, including the use of crowd-sourcing hackathons to solicit solutions to specific problems. However, in some situations greater diversity can mean greater difficulty in terms of reaching consensus and synthesising insights into transdisciplinary knowledge. Overcoming cultural differences and building mutual trust between disciplines, sectors, and countries requires time and long-term investment (Colman et al., 2021[75]). Beyond the capacity to readily engage a diversity of stakeholders, there has been a need to involve targeted actors in a strategic way. Some jurisdictions have had success using programmes specifically designed to connect partners with complementary knowledge, expertise, and resources. Informal connections can also be important for accelerating the participation of stakeholders with knowledge, skills, and resources that are aligned with specific needs. In either case, an enabling environment and the right incentives are required for such connections to flourish.[6]

During the COVID-19 pandemic, a number of countries were able to draw on previously established expert networks that were not constrained by conventional disciplinary siloes. As the pandemic has progressed, some countries have been successful in including a broad range of disciplines, in science advisory structures. However, in some cases, the solicitation of scientific advice from multiple sources using untested processes has highlighted the challenge of effectively integrating and interpretating diverse insights. Fragmented engagement of disparate advisory bodies has even been exploited by decision-makers to reinforce pre-selected actions under the guise of scientific credibility (Colman et al., 2021[75]) (Greer et al., 2022[76]). Going forward, it will be important that the broader context and socio-economic dimensions of crises are represented in the composition and operation of advisory structures. Some countries have already taken important steps in this regard.[7] Different stages of crisis management, i.e., preparedness, response, and recovery, may also require the engagement of different areas of expertise. (Cross-disciplinary engagement as it relates to scientific advice is covered in more detail in the second report of this series.)

Improved co-ordination, communication, and collaboration across disciplines has been important also to maximise synergies, pool capacities, and establish interdisciplinary workflows to address complex research questions. Nevertheless, entrenched views on the hierarchy and prioritisation of different types of scientific knowledge have endured among researchers and policymakers (Colman et al., 2021[75]). In this respect, experts have emphasised the importance of long-term investments into interdisciplinary networks and initiatives targeted at improving cross-disciplinary dialogue and trust.[8] With this in mind, it may be necessary for policymakers to revisit and adapt research funding mechanisms and incentives which contribute to the specialised and segmented operation of science systems. To a certain extent, this is reflected in recent adjustments that have been made to funding and evaluation frameworks and the implementation of cross-disciplinary funding initiatives or centres of excellence in many countries.

Recent work has stressed the importance of a wider array of ‘soft skills’ for scientists involved in scientific advisory processes and/or public communication (OECD, 2015[77]) (OECD, 2018[21]). Many of these same skills, such as communication, diplomacy, and open-mindedness are also important for researchers to engage and contribute effectively to inter- or transdisciplinary collaborations. Tensions generated by collaboration between researchers using different or conflicting theories or terms can require open-mindedness, negotiation and mediation, which are not intuitive for many scientists. More must be done to ensure that scientists have the skills, methodologies, and networks to translate diverse data and insights into transdisciplinary knowledge.

The early involvement of industrial stakeholders in national and international response efforts has accelerated knowledge production, technological development, and innovation. Private sector partners were key to supplementing and filling gaps in the capacity of governments and public research systems (Tille et al., 2021[78]) (Iacobucci, 2020[79]). Yet, in a similar way to interdisciplinary partnerships, the effective deployment of science-industry collaborations has been dependent on enduring efforts to foster enabling conditions. Previous analyses have identified a number of important enabling factors, including: long-term investments into discovery research; data sharing infrastructures and processes; public research institutions and infrastructures; and use of digital platforms and technologies (OECD, 2019[80]). Where established public-private partnerships could be leveraged, these accelerated activities to address many aspects of the pandemic, from basic research through to the development and testing of medical equipment and treatments.

During the COVID-19 pandemic, different approaches have been taken to address the differing motivations of industrial and academic contributors. Some projects have intentionally avoided the use of binding contracts and have shared progress and results openly and with high visibility to encourage buy-in from additional contributors.[9] Where there has been less appetite for this level of flexibility, some collaborations have adopted a modular approach, negotiating contractual arrangements once development of a viable product is in sight. In the case of new collaborations and partnerships, investment in the development of transparent communication processes, social capital, and trust have been particularly important to the ability of participants to manage conflicting priorities and expectations. At the same time, the management of conflicting priorities has been enabled by the significant altruism inspired by the COVID-19 pandemic. Under normal conditions, researchers and science policymakers may not be able to rely on similar levels of goodwill.

Reducing bureaucratic procedures has contributed to the capacity of actors to collaborate across sectors and increased the speed and flexibility with which these partnerships could be organised. Novel funding mechanisms may be useful to further incentivise new approaches to collaboration. However, it will be important also for policymakers to evaluate the potential implications or negative spill over effects of divergence from conventional collaboration practices. It is not currently clear what flexible partnership and funding arrangements could mean for other aspects of collaboration, such as risk management, accountability, fairness, and efficiency (Tille et al., 2021[78]).[10]

Finally, the aspect of transdisciplinary collaboration which has, perhaps, presented the greatest opportunity, and in many countries, revealed the greatest shortcomings, has been public engagement and the integration of corresponding insights into research activities and scientific advice Not only has public engagement been a critical tool in fostering and maintaining societal trust in some national response efforts, it has also played a significant role in expediting the collection and use of sensitive data and enabling decision-makers to tailor policy to the needs of specific territories and demographics. With respect to the deployment of PHSMs, vaccines, therapeutics, and diagnostics, policy and science actors have been confronted with multiple barriers to adoption. Effective public engagement has been essential for understanding and overcoming these barriers.

In many countries, engagement of the public in science activities has been embraced as a priority at a high level; however, its translation into action has tended to be relatively limited (Denegri and Starling, 2021[81]). A critical barrier to implementation appears to be a lack of long-term investment into the infrastructure, skills, culture, and other enabling conditions required for effective public engagement. Tacit and diverse knowledge from citizens can provide grounding context and guidance at every stage of research from study design to the final interpretation and application of results (Tan et al., 2022[82]). However, there is a pressing need to address obsolete and deeply-rooted perspectives that would limit interactions between scientific institutions and the public to one-sided communication and ‘education’ campaigns (OECD, 2021[83]). At the same time, the rise of citizen science initiatives warrants more systematic assessment and monitoring to prevent the exploitation of the public and the crowding out of professional scientists.

Effective engagement citizens can challenge accepted dogmas and enable the adoption of radical or experimental approaches, otherwise likely to be assumed impractical.[11] The COVID-19 pandemic has spawned several high-profile and potentially transformative examples. For example, despite being met with resistance from some professional scientists, the Long-COVID movement, initiated by patient support groups, has shed light on a debilitating condition with global relevance (McCorkell et al., 2020[84]). Another pertinent example is provided by the Hack the Crisis movement that has spread across many European Union countries and beyond to democratise the development of innovative solutions to several aspects of the pandemic response.[12] There is a need for science policy to prioritise the development of capacity and mechanisms to encourage and support experimentation, learning, and innovation around public engagement within both scientific and science policy communities.

Ensuring inclusive representation and engagement of disadvantaged and underrepresented populations in science activities

The COVID-19 pandemic has highlighted the need to fully integrate the social determinants of health into public health research and policy agendas. In this regard, the persistence of structural barriers in the representation of marginalised and under-represented groups in general population data has been a major problem. Incomplete or non-representative data limits the ability of researchers and policymakers to understand the experience of vulnerable groups and develop targeted and appropriate interventions. It can also reinforce unfounded biases and result in policies that are ineffective or even harmful.

Established collection methodologies for population data often overlook certain groups (e.g., migrants, prisoners, and seniors (Milan, Trere and Masiero, 2021[85]). These same demographics are often disproportionately impacted by crises and societal challenges. As such, it is not enough for science activities to focus on improving the availability of disaggregated data. Action is also required to recognise the limitations of existing data collection methodologies or technologies and improve the inclusive representation and access of disadvantaged demographics to scientific results. Novel approaches to data collection and governance are needed; however, their development will require engagement with community groups and representatives from target demographics to ensure that structural barriers are identified and addressed effectively (UNICEF, 2020[86]).

In recent years, specific demographic groups have been engaged to design standards and procedures, such as the CARE principles, which aim to make the collection of data, and its subsequent stewardship and use, inclusive, representative, and ethically appropriate (Carroll et al., 2020[87]). More broadly, science policymakers must promote and empower the engagement of underrepresented groups in the development of standards and guidelines to facilitate co-ordination, co-operation, and collaboration in science activities. It will be important that these standards have the flexibility to accommodate differences across jurisdictions and that potential barriers to implementation or unintended consequences are considered ex ante.

In terms of inclusive engagement beyond data collection, partnerships with civil society organisations and community leaders were an important element of COVID-19 response efforts in many different contexts (OECD, 2022[88]). They played a key role in improving visibility and representation of the needs and concerns of 'invisible' and vulnerable demographics. In turn, this has enabled researchers to prioritise the development of scientific studies, insights, and solutions that reflect the challenges and risks disproportionately impacting underrepresented and disadvantaged segments of the population.[13] However, considerations of equity, diversity and inclusion, have been noticeably absent from COVID-19 response efforts in many countries (Gilmore et al., 2020[89]).

Mechanisms to improve and sustain the inclusiveness of the scientific workforce itself, are of paramount importance. There is some concern within the scientific community that the COVID-19 pandemic has disproportionately disrupted the research production of certain groups, such as female researchers who were particularly affected by the additional 'care burden' during lockdowns. There is a distinct possibility that this may impact research careers and the broader composition of the scientific community over the long-term (Vincent-Lamare, Sugimoto and Lariviere, 2020[90]). Moreover, there is a risk that the pandemic's exacerbation of gender disparities in science may also directly reduce the amount of COVID-19 research driven and informed by women-centred issues (Pinho-Gomes et al., 2020[91]). Still, the effects of the pandemic response on women have been relatively high-visibility and many countries have already responded accordingly.[14] It will be important for science policymakers to take focused action to identify and address less obvious impacts experienced by other groups, such as young researchers from socially deprived backgrounds.

Meta-Theme: Transdisciplinary and reflexive science

Interventions for Resilience	Required Actions
1. Ensure that researchers have the tools, skills, and resources to collect and synthesise multivariate and multidisciplinary data into transdisciplinary and context-specific knowledge.	1.1. Leverage and build on the advancements made in the development and adoption of FAIR data standards during the COVID-19 response. It is important that standards and processes for data management promote international harmonisation, while accommodating the heterogeneity of local infrastructures, capacities, and needs. 1.2. Encourage and support institutions and researchers to consider the full picture when deciding which domains, disciplines, and types of information may be relevant for consideration in their scientific activities. Improving visibility and access to related data and publications is a critical first step. 1.3. Prioritise the development of specialised skills, methodologies, and multidisciplinary networks to support the solicitation, synthesis, and curation of diverse insights and data into multidimensional knowledge.
2. Leverage novel and established collaborations to integrate insights from across sectors and domains and ensure that science-based solutions are rapidly developed and appropriately targeted.	2.1. Leverage established partnerships and other mechanisms (e.g., intermediaries, digital platforms, RIs, etc.) to expand collaborative activities and engage diverse partners with complementary knowledge, skills, and resources. 2.2. Improve co-ordination, communication, and collaboration across research infrastructures and institutes to establish interdisciplinary clusters and workflows, pool capacities, and maximise the realisation of synergies in national science systems. 2.3. Support and incentivise the development and adoption of novel business and funding models to ensure that the conflicting motivations and priorities of potential contributors do not prevent or impede productive collaboration. 2.4. Prioritise long-term investments into the infrastructure, skills, culture, and enabling mechanisms required to engage and integrate tacit and diverse knowledge from the public into science activities at all stages of the research process.
3. Prioritise the inclusive representation and engagement of disadvantaged and underrepresented populations in science activities by institutionalising equity, diversity, and inclusion (EDI) as a priority in funding and evaluation frameworks.	3.1. Improve the availability of disaggregated data (i.e., age, race, sex) and address under-representation within, and access to, population data resources. It will be important to recognise and reverse exclusion by mitigating the limitations of digital technologies and addressing structural issues that contribute to the 'digital divide'. 3.2. Prioritise the inclusive engagement of underrepresented demographics, in terms of contributing scientists and public representatives, in the full spectrum of scientific activity, from the design of studies to the interpretation and application of results and data. 3.3. Ensure that disadvantaged populations and LMICs are engaged and empowered in processes to develop standards and guidelines for the co-ordination of science activities and the development of interoperable and accessible data and results.

Section endnotes

[1] Digital technologies have also been used to support context-specific analyses, such as the utilisation of Twitter data and machine learning to assess wellbeing metrics and patterns in specific United States cities during COVID-19 lockdown periods (Levanti et al., 2022[151]). In another example, SciSight, an AI-enabled visualisation tool, has enabled researchers to quickly and intuitively explore links between concepts in the CORD-19 dataset of research publications (https://scisight.apps.allenai.org/).

[2] Data sharing initiatives developed in response to the COVID-19 pandemic have leveraged existing work, such as the ORCID DataCite Interoperability Network (ODIN) developed in 2012 to streamline the association of datasets with creators using interoperable metadata. The metadata allows connectivity and communication between data owners and potential users to address concerns regarding data quality, context, and appropriate attribution of credit (Bryant, 2013[126]). As a result, researchers are able to link data on the European Union's COVID-19 platform with ORCID accounts to provide clarity on its provenance.

[3] In the international context, Global.health was launched in February 2020 as an international collaboration with funding from Google, the Rockefeller Foundation, and Oxford Martin School to create a trustworthy resource for up-to-date infectious disease data (https://global.health/about/). The platform provides centralised open access to verified case-level data from diverse communities around the world. It aims to support and accelerate the efforts of scientists, public health officials, and others in preparing for, responding to, and mitigating the burden of disease outbreaks. As of June 2020, the network had assembled data for more than a million cases in 142 countries (Johnson, 2020[149]). This was used to identify the 5-14 day incubation period of the SARS-CoV-2 virus in the early days of the pandemic (Kraemer, 2020[150]).

[4] The University of Hong Kong School of Public Health employed established epidemic nowcasting expertise to inform initial policy decision-making during the pandemic response. Nowcasting is a multidisciplinary short-term forecasting methodology. In the context of the pandemic, pathogenic, epidemiologic, clinical, and socio-behavioural data were integrated from various sources to understand the unfolding nature of the outbreak and to assess and forecast transmissibility, epidemic size, and identify emerging variants (Wu et al., 2021[19]). (This case study is covered in additional detail in report 2)

[5] The role of RIs is covered in greater detail in the first report of the series.

[6] In Finland, a novel methodology has been developed to enable the expedited advancement of novel multidisciplinary collaborations during the pandemic. Fast Expert Teams uses an iterative modular approach and digital platforms to foster connectivity between project contributors (Futuremote, 2020[152]). The approach is driven by participants, who leverage their own established relationships and social capital to bring in additional experts and create new connections. In a similar way, Crowdfight covid-19 is a non-profit initiative launched during the pandemic response (https://crowdfight.org/about-us/). The purpose of the platform, funded partially through a grant from under the EC Horizon 2020 programme, is to connect scientists (and others) from all disciplines to those working on the frontlines of the pandemic to support them in any way required. The platform receives requests from researchers regarding collaboration and taps into the existing network to find appropriate experts to be engaged. In this respect, the organisation is striving to eliminate two barriers currently impacting cross-disciplinary collaborations: difficulty finding the right expert and lack of credit for minor contributions. Since its creation more than 45,000 volunteers have joined the platform globally to contribute to over 900 requests.

[7] SciBeh was developed during the COVID-19 pandemic to support the contribution of behavioural sciences (https://www.scibeh.org/). The digital platform provides a variety of tools to: improve the connectivity of policy-makers and communication professionals with relevant experts; the consolidation of emerging knowledge into a centralised and accessible evidence base; and co-ordination, harmonisation, and acceleration of crisis relevant research. SciBeh released a guide to address misinformation, *The COVID-19 Vaccine Communication Handbook*, in addition to working on other related projects. There are also examples where science policymakers have made attempts to integrate behavioural and social sciences into policy development at the national level. Impact Canada launched

Behavioural Science (BeSci) in March 2020 to support policymakers in promoting behaviours identified by public health experts as key to decreasing the spread of the SARS-CoV-2 virus (Impact Canada, n.d.[153]). BeSci is a multidisciplinary initiative that uses digital and field-based data collection tools to generate and translate data on public knowledge, perceptions of risk, and behaviours into policy-relevant insights.

[8] In France, the REACTing (REsearch and ACTion targeting emerging infectious diseases) consortium was launched in 2013 to co-ordinate national infectious disease research (https://www.iame-research.center/associated-organisations/reacting-2/). This multidisciplinary initiative brings together a variety of experts, teams, and labs and has a broad mandate ranging from fundamental research to the social sciences. The consortium provided seed funding to a significant proportion of French research undertaken in response to the pandemic. On the other hand, in Australia, the country's then Chief Scientist created the Rapid Research Information Forum (RRIF) in 2020 to be managed by the Australian Academy of Science (https://www.science.org.au/covid19/news-and-resources). It was intended as a mechanism to convene relevant experts from across scientific disciplines to address the COVID-19 pandemic as it evolved. It has since been replaced by the Rapid Research Information Reports which are prepared by the National Science and Technology Council with input from RRIF participants.

[9] The COVID Moonshot project is an international open-science consortium of public sector and academic scientists, pharmaceutical research teams, and students working together to develop accessible oral therapeutics for LMICs and vulnerable communities. Largely spurred by spontaneous virtual collaboration through Twitter, the public-private collaboration has attracted significant support from key funders, such as the University of Oxford and the Wellcome Trust and has grown to upwards of 200 collaborators, including national and international academic and industrial groups (Kresge, 2021[154]). The initiative has adopted an Open Science approach, which has been successful in identifying new therapeutic compounds but has struggled to navigate tensions between commercial drug discovery business models and providing equitable access to treatment for all.

[10] Operation Warp Speed (OWS) was the United States COVID-19 vaccine development initiative under which, USD 18 billion was allocated in less than a year (Arnold, 2022[155]). It deviated from standard contracting and scientific consensus processes to accelerate the development of novel solutions for detection, treatment, and prevention of virus transmission. Lessons from OWS can be constructive to the development of more flexible funding instruments, while maintaining caution that other dynamics, such as transparency and deliberation are not entirely relinquished. For example, while the primary use of flexible contracting mechanisms referred to as Other Transaction Authorities (OTAs) can expedite the development of funding agreements, they are not subject to most of the regulations common to standard federal procurement and have been criticised for their potential to circumvent the fairness, accountability, and transparency that is generally required of federal funding. To enable swift advancement, OWS processes favoured top-down decision-making in the place of the government's standard consensus methodology for scientific advice.

[11] The Coronavirus Makers group in Spain grew to over 17,000 members during the pandemic. It represents a decentralised initiative across multiple cities and communities that aims to support first responders and frontline workers. The group contributed to three primary streams of work: the 3D printing of facial shields; repurposing snorkelling masks into adaptors for respiratory filters and automatic respirators; and developing automatic respirators for hospitals. On a global scale, a similar initiative is represented by Helpful Engineering, which is an international open-source platform dedicated to co-ordinate and target capacity toward systemic challenges (https://helpfulengineering.org/). During the pandemic, the platform brought together volunteers to help address hospital PPE shortages through the design and development of face shields (Heilweil, 2020[156]).

[12] The hackathon response to the COVID-19 pandemic started in Estonia, organised by Accelerate Estonia, and has since spread around the world, culminating in a Global Hack. During Hack the Crisis events, participants form virtual teams collaborated on the development of new technology-based solutions for various aspects of the pandemic response. The movement has brought together thousands of individuals from the public and private sectors, including researchers, educators, students, policy-makers, and others. One of the solutions developed by the Estonian initiative was a digital system to support the government in tracking and forecasting PPE needs. The system has been used by more than 300 institutions in the country (Hankewitz, 2020[157]).

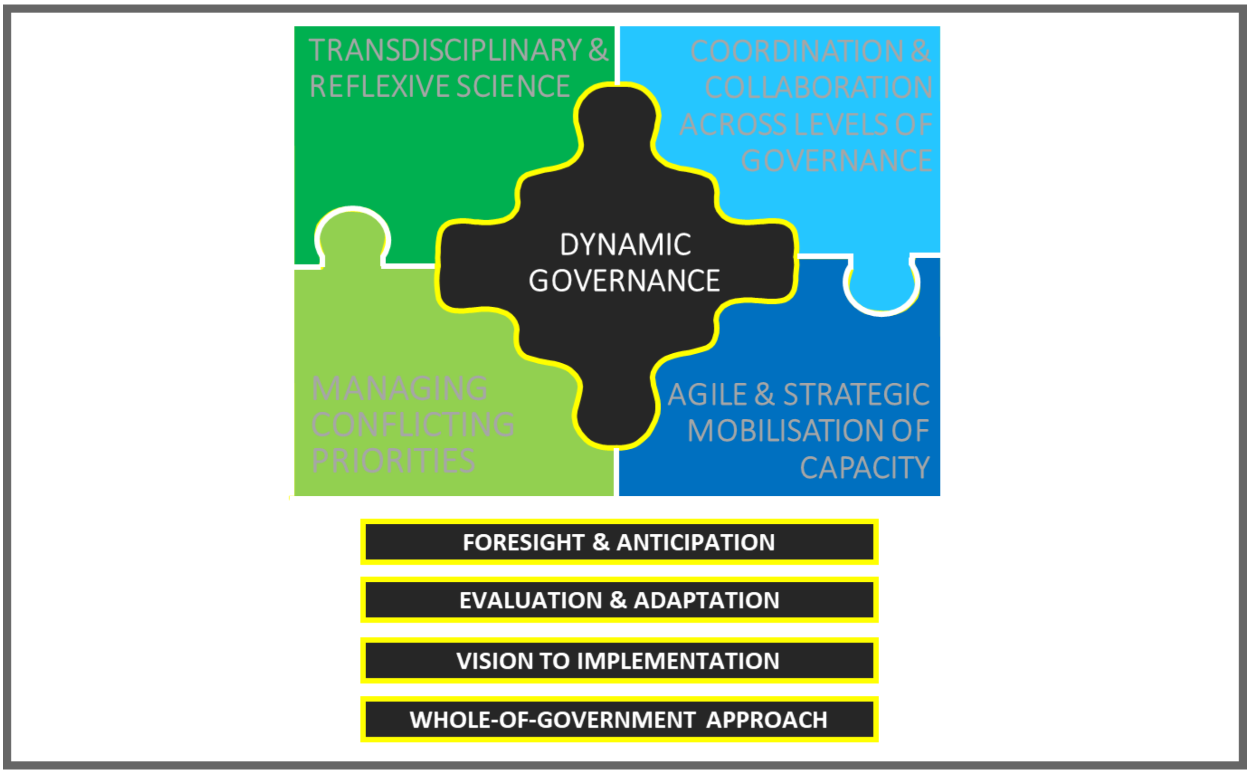
[13] Portugal launched several research programmes targeted toward understanding the impact of the COVID-19 pandemic on underrepresented and disadvantaged demographics. For example, the Foundation for Science and Technology opened a call in January 2021 to provide special support to R&D projects related to understanding the impact of the pandemic on hate crimes, violence, and hate speech. Gender Research 4 COVID-19 was introduced even earlier, in May 2020, to provide support for research to understand the impacts of the pandemic on gender inequalities and violence against women (EC-OECD, 2023[95]). Another example is provided by efforts of the National Council for the Evaluation of Social Development Policy (CONEVAL) of Mexico. The organisation completed an ex ante evaluation to better understand the impacts of the pandemic on poverty and how best to use established social services to address corresponding issues (OECD, 2022[170]).

[14] As part of the national COVID-19 response and recovery strategy, Australia committed to expanding assistance targeted to supporting the entry, re-entry, retention, and advancement of women in the STEM workforce. The country's chief scientist released a briefing, outlining variables likely to impact the gender balance of the scientific workforce. These included disproportionate growth of domestic workloads and caring responsibilities for women, reduced career opportunities, and job insecurity due to higher proportions of women being employed in short-term and casual positions (Rapid Research Information Forum, 2020[158]). It was highlighted that anticipated reductions in support for equity programmes due to reallocation to COVID-related funding would likely reverse recent gains in STEM workforce diversity. To combat this, a variety of initiatives were introduced.

5 Dynamic and system-oriented governance of science for society

Dynamic processes and mechanisms for the governance of science systems and development of science policy, are needed to prepare for, respond to, and recover from crises more effectively. Traditional approaches are not necessarily well suited to dealing with critical aspects of complex crises and societal challenges. The pandemic has had implications for, and been impacted by, a wide range of domestic and international factors, involving multiple policy domains. Strategic foresight and surveillance are important tools for preparation and proactive response, but these alone, are not sufficient. Structural change to policy development processes is needed to more effectively capitalise on insights from evaluation, experimentation, and from beyond science.

Figure 6. Meta-theme: Dynamic governance and corresponding interventions



Note: Figure 6 provides a review of the interventions proposed for the meta-theme: Dynamic and system-oriented governance (outlined in yellow).

Investing in foresight capacities to enable the conversion of potential future challenges and needs into current actions

Prior to the COVID-19 pandemic, there was already growing international recognition of the need to adopt a multi-sector and multidimensional approach to threat surveillance. An 'all-hazards' approach was being promoted by intergovernmental initiatives, such as the Sendai Framework, to ensure that comprehensive action is taken to assess risk and uncertainty and facilitate preparation for potential future shocks (UNDRR, 2015[92]). Early-warning systems for public health emergencies and other crises were already being transformed by digitalisation, e.g., Big Data and digital crowdsourcing platforms (OECD, 2015[93]). COVID-19 has bolstered this trend.[1]

Shortcomings experienced by many countries in responding to the COVID-19 pandemic have underscored the need to integrate strategic foresight capacities into conventional policy-making processes and adapt established structures to cope with complex hazards that transcend conventional siloes. Hazards capable of triggering cross-border emergencies or complex societal challenges require inclusive and dynamic collaborations that address the needs of different demographics and regions. It is important also that potential relationships between hazards are considered to ensure that efforts to respond to one crisis do not inadvertently aggravate another (see section on transdisciplinary and reflexive science).

Strategic foresight and emergency preparedness activities provide a valuable opportunity to improve relationships and communication between scientific and policy communities. Yet, in the aftermath of the pandemic, many countries have noted that functional connections between foresight and policy development processes have been largely absent (Dal Borgo and Monteiro, 2022[94]). Moreover, only a handful of the science advice initiatives that were reported on by OECD countries over the course of COVID-19 pandemic were explicitly described as relating to foresight, preparedness, risk assessment, or resilience (EC-OECD, 2023[95]). This disconnect likely contributed to the lack of preparedness exhibited by many countries in responding to the COVID-19 pandemic, despite prior warnings issued by multiple high-profile experts over the past decade regarding the imminent and significant risk posed another deadly infectious disease outbreak (Mahroum et al., 2022[96]). It also speaks to the need for a fundamental shift from an underlying culture that often shies away the translation of risk assessment into concrete action.[2] Many countries have active foresight communities and although these have rarely been linked with science advisory processes during the pandemic, there are opportunities now to use strategic foresight to inform future national and international actions during the recovery phase and in preparing for the next pandemic.[3]

Going forward, collaborative participation of science and policy actors will be important in the creation and operation of early warning and disaster risk surveillance systems, foresight exercises, and routine crisis response drills and training. This will help ensure that mutual understanding and trust is already established between experts and policymakers to facilitate the translation of science advice into policy decisions during a crisis. Continued engagement of a diversity of scientific expertise will be necessary to ensure the integration of recent and forthcoming innovations into routine surveillance capacities and the appropriate contextualisation of resulting data. In this context, it will also be important for researchers and science policymakers to use strategic foresight to inform the collection of longitudinal data in anticipation of its potential relevance to future crises or societal challenges and to consider which indicators to use to inform national response efforts.[4]

Investing in the infrastructure, skills, and tools required for evaluation, adaptation, and dissemination of policy learnings and good practice

The changing nature of the pandemic and lack of systemic action, in many countries, to monitor and document mitigation measures has limited the sharing and adoption of good practices across countries. Science advice structures, PHSMs, and vaccine and diagnostic deployment strategies have mainly been nationally focused and with little attention to implications at the international scale. In many respects, mitigation actions have also neglected to integrate important learnings from previous crisis response efforts. While this has not been the case in all countries, it has been remarkably common and confirms a longstanding tendency for evaluation to be viewed as an administrative hurdle rather than an opportunity for improvement. The manner in which science programming is funded in many countries encourages policymakers to prioritise the development of novel initiatives rather than revisiting and recalibrating existing policies to improve outcomes and maintain their relevance in a changing environment (OECD, 2010[97]).

Addressing this structural challenge will require the transformation of policy development and funding structures to integrate a more future- and system-oriented mindset. The careful consideration and design of evaluation frameworks is also key to ensuring that the indicators being measured shape, measure, and incentivise desirable outcomes, particularly as demands and expectations evolve. Current evaluation processes are based primarily on traditional metrics, such as publications, patents, and funding. This incentivises approaches to science policy and activity that are preoccupied by what and how much and lack a similar focus on who or why (Schot et al., 2017[98]). Conventional science metrics have also contributed significantly to the specialisation and fragmentation of science systems and made it more challenging to advance global Open Science agendas. (This is covered in additional detail in the sections on transdisciplinary and reflexive science and conflicting priorities, respectively.) Going forward, evaluation frameworks must include criteria and indicators that reflect a shift in focus from individual scientific excellence to the full range of demands on science.

Improving the collection and accessibility of data related to project, programme, and policy evaluations is an important first step to ensure that experience feeds back into policy design. This is necessary to improve awareness of established policy and science system capacities, which can enable science policymakers to make systemic and long-term investments. As the COVID-19 pandemic transitions to recovery, such data can support holistic reflection of the actions that were taken during the response.[5] Policymakers will need to make strategic decisions on whether to consolidate, repurpose, sustain, or suspend new initiatives, while also considering their alignment with pre-existing activities. In addition, evaluation data is key to improving the ability of scientists and science policymakers to understand how, why, and to what extent policies and science activities effectively contribute to long-term outcomes and to identify and address unintended consequences of policy decisions.

Where countries have had the culture, skills, and processes in place to facilitate and encourage evaluation of the science system and science policy, it has provided an important enabling environment to support the application of lessons and good practice in the context of crisis response. [6] In many countries this has not been the case. Historically, evaluations have been undertaken and lessons drawn from previous public health crises, such as the SARS and MERS outbreaks. Yet, there appears to be a consequential disconnect between the process of evaluation and the translation of outputs into actions necessary to affect corresponding change.[7] Bridging the divide between the realisation of learnings and their implementation may require decision-makers to designate ‘change agents’ – individuals or structures - with the authority to influence the adaptation or transformation of government structures. In this regard, it is important to recognise that some of what has occurred, such as the reduced emphasis on profitability in some public-private partnerships or reduction in some bureaucratic processes, has only been made possible because of the critical and urgent nature of the emergency situation.

In a similar vein, traversing boundaries between evaluation and reaction will enable policymakers to leverage and translate the experience of other countries. To a certain extent, necessity spurred by the prevalence of infectious disease outbreaks has normalised the sharing and adoption of good practice across borders in certain regions, such as South-East Asia. The pandemic response has highlighted a noticeable contrast with other regions where there has been limited willingness or appetite to share and make use of evaluation insights across borders (Bortolotti and Murphy-Hollies, 2022[99]). Some have speculated that this is the result of western exceptionalism; however, it is also possible that it relates more to the limited visibility that decision-makers have into the current capacity of science systems and related sectors or the impacts of science policy.

Improving the translation of high-level objectives into science policy actions

At a meta-level, the COVID-19 response has highlighted the need for structural change to the way that science systems are governed and how science policy is developed. A linear perspective of science underlies much of existing science policy in that its general aim is to address barriers to the optimisation of the quantity and quality of knowledge (and from an innovation perspective, its translation into useable products) (OECD, 2020[100]). In this respect, challenges can stem from the inefficient operation of science systems or market failures (Ghosh et al., 2021[101]). The growing prevalence and prominence of complex societal challenges and crises, such as the COVID-19 pandemic, has spurred recognition that a different approach, one more conducive to recognising and integrating the multiple interconnections and linkages to societal systems and valuing outputs beyond new scientific knowledge is required.

The interdependence common to modern societal systems, and the volatile and cascading nature of many contemporary threats, requires systems-based policy to address misalignment between the supply of knowledge and areas of critical need (OECD, 2020[100]). Current science systems and policy development processes are challenged in directing scientific advancements towards specific challenges or normative priorities due to a lack of shared vision and targeted funding (Weber and Rohracher, 2012[102]). Ambitions to mobilise science systems to absorb, respond to, and recover from crises and societal challenges as they emerge represent a distinct break from the status quo, meaning that distinct policies and policy development processes are required. In this respect, novel and experimental configurations of actors, institutions, and practices are needed to improve the resilience of science systems and the relevance of outputs to emerging crises, challenges, and the everyday lives of individuals (Grillitsch, Hansen and Madsen, 2020[103]).

Traversing the divide between a linear and systems-based approach to policy development requires an appraisal of the structures, processes, and skills that form the basis of current policy institutions and a willingness to break from convention. In many respects, the shortcomings of national responses to the COVID-19 pandemic have highlighted areas where, while learnings and good practice indicate a need to shift the status quo, the implementation of change has been stalled or undermined. For example, while strategic foresight and public engagement have both been recognised as important tools to anticipate and address emerging risks and foster resilience and adaptability, many countries have had limited success in uniting related science capacities with appropriate areas of government. Even with access to associated resources, there is often a step missing in the translation of foresight into policy decisions as these methodologies are generally designed to envision and understand possible futures rather than proceed towards a particular future (Tonurist and Hanson, 2020[104]). Conversely, traditional policy development is largely reactive, or at minimum, reliant on linear causality and closed futures that are informed predominantly by past patterns (Henriksen, 2013[105]).

New and innovative processes and mechanisms are needed to bridge and translate insights resulting from relatively novel functions, like strategic foresight and public engagement with established policy development processes. Disconnects between these areas and conventional policymaking also demonstrate the need to ensure that, as the vision, values, and intentions of science policy evolve, these changes are also reflected in how policy is developed and implemented. Vested and deeply rooted interests, commitments, logics, and values generally form the foundation of convention and can reinforce prevailing practices and assumptions (Schot and Steinmueller, 2018[29]).

The dislocation of a policy's aim from its design can often be exacerbated in its implementation. Policy development and execution generally involve distinct stakeholders or even different agencies. In many instances, preparedness drills were led by public administrations and did not involve the scientific community. The results of these drills have been noticeably absent in the pandemic response. For example, the United States has received criticism for its failure to apply guidelines outlined in a playbook developed by the National Security Council in 2016 following the Ebola crisis (Diamond and Toosi, 2020[106]). Similar failures have occurred in other countries, where weaknesses identified by pandemic preparedness exercises, including shortages of personal protective equipment (PPE), were not addressed prior to the COVID-19 pandemic. The Global Health Security Index (GHSI), released in 2019, provides a thorough analysis of the capacity of 195 countries to avert or respond to outbreaks.[8] The observation that rankings of the GHSI are not predictive of the effectiveness of national responses to the COVID-19 pandemic is troubling (Abbey et al., 2020[107]). This disconnect between preparedness exercises, the evaluation of previous efforts to respond to crises, and actual response efforts illustrates that there is a critical need to bridge the gap between policy development and its implementation and adaptation.

Methodologies and mechanisms exist to incorporate scientific and other contextual knowledge at all stages of the policy cycle, from design to implementation, evaluation, and augmentation. At the same time, the pandemic response has demonstrated important shortcomings here, such as persistent tendencies for policymakers to favour the engagement of certain disciplines in science advice structures and the advancement of certain activities in research agendas. For example, it appears that research agendas prior to COVID-19 largely neglected the importance of the non-biomedical aspects of infectious disease management. This includes many of the areas that have posed the greatest challenge to policymakers, such as social interventions, risk communication and behaviour, and bridging pandemic preparedness with response and recovery.

Many aspects of the response were unprecedented and required a departure from established approaches. In these instances, it was important that policymakers had the capacity and willingness to experiment, fail, and learn. Dynamic processes, including experimentation and the development of provisional, and incremental initiatives can create space for science policymakers to balance flexibility and stability and more effectively manage a situation's interdependencies with contingencies (Kuhlman and Rip, 2014[108]). In dealing with complex crises and societal challenges, adaptability is important because, as with many aspects of the COVID-19 pandemic, it is often the case that prior knowledge and good practices have not yet been developed (Chataway et al., 2017[109]). Flexible policy and programming can also be used to encourage or, at a minimum, enable researchers and other stakeholders to adopt innovative and experimental ways of working. For example, although somewhat outside the scope of science policy, some experts have noted how the activation of emergency use authorisations by many national pharmaceutical regulatory bodies might provide an opportunity to expand the use of experimental 'regulatory sandboxes' from other domains, such as fintech, to pharmaceuticals.

Not only does experimentation require policymakers to have appropriate skills and tools, it also requires a mindset and culture that encourages evaluation and reflexivity, a willingness to undertake critical self-reflection and the ability to integrate of diverse insights, (Lindner, 2016[71]). The pandemic response has illustrated the limitations of science and science policy as they currently operate and the importance of mitigating unrealistic expectations regarding their ability to steer a situation characterised by complexity and uncertainty without some amount of course-correction. In both respects, effective engagement of public and private sector actors and citizens in the development of science policy may provide an effective way forward.

Transdisciplinary knowledge, including insights from a broad diversity of scientific disciplines as well as civil society can provide guidance to ensure real-world suitability of policy design and implementation. Stakeholders from outside of science can play a critical role in informing the development and co-ordination of top-down priorities with bottom-up initiatives that reflect pressing and unmet needs, challenges, and risks. In this respect, it is important that bureaucracy does not impede process innovations and novel ways of doing things, which often play a key role in responding to complex crises and societal challenges. In response to the COVID-19 pandemic, some research agencies consulted with a diversity of actors to improve proposed initiatives and proactively address aspects of policy design that did not align with how intended beneficiaries operate.

In a similar vein, public engagement can ensure that the broader context is represented in the governance of science systems and foster shared expectations, understandings, and mutual trust at the science-policy-society interface (Weber and Rohracher, 2012[102]). It has been noted that, in many respects, the most successful national responses to the pandemic have leveraged a whole-of-society approach (OECD, 2022[88]). In several instances this has gone as far as engaging individual citizens as co-collaborators in the development and translation of scientific knowledge into policy decisions and setting broadly relevant and inclusive research agendas.[9] Similar to experimentation, the systematic integration of insights from the public into the development of science policy will require policymakers to build capacity and leadership through reflexive processes and to develop targeted skills, tools, and perspectives (Schot et al., 2017[98]).

Taking a systemic, holistic, and whole-of-government approach to policy development

In addition to science policy being more connected to direct beneficiaries and civil society, it will be important for it to both reflect on and be reflected in the mandates and corresponding initiatives of other policy domains. Complex crises and societal challenges invariably impact and require co-ordinated action from multiple policy domains. The COVID-19 pandemic and subsequent response efforts touched virtually all aspects of society, requiring important actions to be taken outside the direct remit of research, or even health, ministries and agencies. A whole-of-government approach is foundational to the ability of policymakers to coherently and effectively prepare, respond, and recover to complex crises and societal challenges. An appreciation of the interdependencies and connections between policy domains can help policymakers to balance the pursuit of efficiency with the need to foster resilience. This requires coherent and connected governance mechanisms between ministries that provide policymakers with the ability to guide interactions between different policy domains.

The pandemic response has demonstrated the extent of the intersections and linkages between different policy domains and the fragmentation that currently characterises the policy landscape in many countries. In some respects, the rapid response that the pandemic necessitated has also further exacerbated existing structural siloes between policy areas and departments. Many countries were ill-equipped to co-ordinate the governance of disparate departments and agencies in national and subnational science systems, let alone co-ordinate response efforts horizontally across diverse policy domains. Similar to other areas where structural transformation is required, such as public engagement and strategic foresight, recognising the need for change is only the first stage in the process. Established sectoral siloes red tape, vested interests and different values pose significant barriers (Schot and Steinmueller, 2018[29]) (Weber and Rohracher, 2012[102]). The transaction costs in trying to work across different silos can be prohibitive. However, deeper assessment of the learnings yielded by the pandemic response also reveals the opportunities presented by improving cross-government co-ordination.[10]

As raised in section 1, future-focused and long-term investments into science systems are important to ensure that the capacities and infrastructures needed to prepare, respond, and recover from crises and societal challenges are in place. Non-science policymakers can provide insights regarding their mandates, ongoing initiatives, and sector-specific dynamics to support scientists and science-policymakers in leveraging synergies, limiting unnecessary duplication, and addressing gaps that are evident across policy domains. These insights can also be a key first step to integrating societal and policy imperatives into the scientific research agenda and ensuring that related activities reflect the broader operating context, e.g., national history, culture, and regulatory and administrative regimes. Initial guidance from other policy domains may address some of the challenges currently impeding public engagement by focusing attention on specific areas and enabling the solicitation of inputs to be more targeted.

Cohesive, whole-of-government support is an important enabler of the long-term, and large-scale funding commitments required to support science systems in operating at the cutting edge of research and fostering operational resilience. Similarly, connectivity and mutual exchange between science and non-science policymakers can facilitate the swift integration and uptake of scientific insights and innovations in relevant sectors (See chapter 1 for additional detail). Conversely, optimising the flow of sector-specific data into science activities can reduce duplication and enable more efficient resource allocation, enable a greater diversity of potential solutions, and improve the development of more effective and context-specific policy (OECD, 2020[110]). In this context, it is important for science policymakers to take the initiative to lead and experiment with novel approaches to achieve cross-government co-ordination, communication, and collaboration. The ability to leverage corresponding infrastructures, skills, tools, and culture will serve either as a critical enabler or a barrier. An expanded focus on strategic foresight can encourage such cross-government collaboration around critical issues that require new scientific insights or technological developments (Tonurist and Hanson, 2020[104]).

At the same time, it is important to recognise the longstanding and deeply embedded nature of the divisions between policy domains in many jurisdictions. For decades, siloes have been a defining characteristic of how government policy is organised and this reflects the similarly fragmented organisation of industrial and academic domains (Hynes, Trump and Linkov, 2019[111]).This was evident in the early days of the pandemic response when the parameters of the crisis were limited predominantly to public health and inadequate consideration was given to dimensions of public life that would be critically effected by PHSMs. Making cross-government collaboration the expectation rather than the ideal in responding to societal challenges and crises and in the development of far-reaching and transformative science policy will require the concerted attention of policymakers. It is likely the such collaboration will need to be established incrementally over time and through a process of learning and iteration.

Meta-Theme: Dynamic and System-Oriented Governance

Interventions for Resilience	Required Actions
1. Invest in fostering and connecting foresight capacities to policy development processes to enable the conversion of potential future challenges, needs, and opportunities into current actions.	1.1. Prioritise investment in and use of strategic foresight capacities and processes to predict and monitor high-probability and/or high-impact risks and hazards. It will be important to develop and maintain communication between these capabilities and government decision-makers. 1.2. Use strategic foresight tools to improve the resilience of science systems and related policy domains and proactively invest in their ability to address ongoing and future crises. 1.3. Improve the capacity for quantitative and qualitative data to be collected and curated proactively as their relevance to potential future crises and societal challenges are anticipated.
2. Invest in the infrastructure, skills, and tools required to evaluate policy and other initiatives and facilitate the integration and dissemination of learnings and good practice to improve the development and adaptation of policy across borders.	2.1. Facilitate a shift in policy culture by making iterative and long-term improvement a priority for existing policies and funding processes in addition to the development of novel initiatives. Ensure that evaluation frameworks are updated to reflect contemporary objectives. 2.2. Improve the collection of the quantitative and qualitative data required to evaluate the outcomes of policy, programming, and other initiatives. It is important that there are established avenues available to science policymakers to assess how, why, and to what extent science policy and science activities contribute to long-term priorities as well as potential unintended consequences. 2.3. Reflect carefully and systematically on actions taken during the pandemic to ensure that strategic decisions are made during recovery to sustain, consolidate, repurpose, or suspend new initiatives and align those that are maintained with the existing policy mix. 2.4. Prioritise the evaluation of national efforts to prepare for and respond to crises and normalise the transparent sharing and integration of learnings between countries and across different policy areas.
3. Improve the translation of high-level objectives into practical and effective policy decisions by encouraging self-reflection, experimentation, and broader participation in the development and implementation of science policy.	3.1. Utilise established methodologies and relevant scientific and contextual knowledge to design strategic science policy. Effective engagement between actors traditionally responsible for policy development and those with a role in implementation is important to cultivate coherence and support the realisation of underlying objectives. 3.2. Foster iterative feedback and communication mechanisms at the science-policy-society interface to co-ordinate the development of top-down priorities with bottom-up initiatives targeted to unmet needs, challenges, and risks and ensure alignment between science activities and the broader policy context. 3.3. Encourage and support policymakers in adopting experimental approaches, including for public engagement, when developing policy and programming. The aim should be to empower beneficiaries to adopt innovative and experimental ways of working, whilst eliminating unnecessary bureaucracy and reducing administrative burden.

4. Take a whole-of-government approach when addressing complex crises and other societal challenges to ensure that actions taken to prepare and respond are coherent, holistic, and catalyse necessary structural transformation.	4.1. Recognise and integrate interdependencies and linkages between policy domains into science policy development processes to facilitate the development of systems-focused science policy that is broadly relevant and encourage other policy domains to adopt similar approaches. 4.2. Initiate and lead the development of mechanisms to enable scientific dialogue and collaboration across government departments and agencies. Mutual contributions will be important to ensure that science policy is aligned with emerging sector-specific challenges and opportunities and to facilitate the integration of scientific insights and innovations into other policy domains. 4.3. Invest in experimenting with and cultivating the resources, skills, tools, and culture science policymakers require to motivate cross-government co-ordination, communication, and collaboration.

Section endnotes

[1] The Argentinian Public Health Research on Data Science and Artificial Intelligence for Epidemic Prevention (ARPHAI) is a research consortium dedicated to using technologies, such as AI and data science, to anticipate and respond to epidemiological outbreaks. In response to learnings from the COVID-19 pandemic, its current focus is on upgrading and scaling up the national electronic health record (EHR) system. The consortium has been included in the Global South AI4COVID Program, the result of a bilateral collaboration between Canada and Sweden that is focused on using AI to support the response of low- and middle-income countries to the covid-19 pandemic.

[2] At the beginning of 2021, the International Science Council announced the development of a COVID-19 Outcome Scenarios Project in collaboration with the WHO and the United Nations Office for Disaster Risk Reduction (UNDRR). A report was released in May 2022 outlining drivers and potential outcomes of the COVID-19 pandemic over the next five years and proposes several alternative global COVID-19 futures to support policymakers in taking appropriate action (International Science Council, 2022[135]). The report considers impacts of the pandemic beyond its direct impact on health. It concludes that many governments have failed to prioritise factors likely to have the most substantial impact, such as supports for vulnerable demographics, education systems, and mental health services.

[3] Various foresight initiatives have been undertaken at the national level. Policy Horizons Canada is an organisation that was developed to support the federal government in integrating strategic foresight into policy development processes. In July 2020, Policy Horizons Canada released a report, Foresight on COVID-19: Possible shifts and implications, which provides country-specific insights regarding plausible mid- to long-term consequences of the pandemic, as well as guidance on how to apply foresight in policy development (Policy Horizons Canada, 2021[159]). Several scenarios are addressed, based on work with a Federal Foresight Practitioner Network, specifically to address assumptions likely to be made by policymakers, such as quick economy recovery following conclusion of the pandemic.

[4] The use of leading versus lagging indicators appears to have contributed significantly to the response strategies adopted by different countries. Leading indicators are forward-looking. They occur prior to a targeted event and can provide insight into what may happen within a given future timeframe (Redding, 2020[160]). Conversely, lagging indicators occur because of the event and provide insights into what has happened. The categorisation of indicators in this way depends on the phenomenon in question. To a large degree, economies that used leading indicators, such as adherence to PHSMs (e.g., New Zealand, Chinese Taipei, Viet Nam, Korea, Australia, and People's Republic of China) were better equipped to anticipate the actual severity of the pandemic and were thus positioned to adopt aggressive strategies. In contrast, most OECD countries prioritised the use of lagging indicators, such as hospitalisation and fatality rates, which inherently meant that they were reacting to what had already happened rather than acting proactively to circumvent potential futures. These countries predominantly used a risk-based approach to mitigate fatalities (Hassan et al., 2021[53]).

[5] The *Comparative COVID Response* (CompCoRe) project (https://compcore.cornell.edu) and the *Evaluation of Science Advice in a Pandemic Emergency (EScAPE) project (https://escapecovid19.org/about/),* were supported by the United States National Science Foundation in the early stages of the pandemic. Both have worked with international partners to collect information and data from different countries to assess the performance of their science advisory systems. Whilst the methodological approaches are different, both studies consider the pandemic as a unique learning opportunity, with the aim of improving science advisory mechanisms in the future. (Publications from these studies can be accessed via their websites)

[6] While not an official signatory the International Health Regulations (IHR), Chinese Taipei used the IHR Joint External Evaluation (JEE) tool to evaluate the island's epidemic preparedness (Lee, 2020[161]). Subsequent action was taken to update Chinese Taipei's legislation, to detect, report, and respond to epidemics in accordance with the IHR. These actions, such as the introduction of the Communicable Disease Control Act, have allowed the territory to respond swiftly and decisively during the initial and consequential stages of the COVID-19 pandemic. The JEE tool

was first introduced in 2016 and has been updated multiple times, most recently in 2018 and 2022. It was developed by the WHO to serve as a standardised metric to measure capacity to prevent, detect, and respond to public health emergencies. As of June 2022, 116 countries had used the first and second editions. The most recent iteration includes lessons from the COVID-19 pandemic based on recommendations from global experts of the WHO, partner institutions, and member states.

[7] In 2021, the Auditor General of Canada released an evaluation of the efforts taken by the Public Health Agency of Canada to prepare for and respond to the COVID-19 pandemic. The agency itself was created in response to an evaluation of the national response to the 2003 SARS outbreak (McAteer et al., 201[162]). The application of learnings following the 2009 H1N1 pandemic resulted in significant subnational collaboration during the COVID-19 pandemic in line with the Federal-Provincial-Territorial Public Health Response Plan for Biological Events (Office of the Auditor General of Canada, 2021[163]). However, the auditor's report identifies several important limitations in the application of other learnings. Response plans have not been regularly updated and testing exercises were not conducted with subnational partners prior to the pandemic. Well-known issues with health surveillance and data exchange between the Public Health Agency of Canada and subnational partners were not adequately addressed. Additional challenges were posed by the agency's obsolete digital infrastructure.

[8] The Global Health Security Index (GHSI) was developed to assess the ability of countries to avert and mitigate outbreaks and ranks countries based on 85 sub-indicators that relate to prevention, detection and reporting, rapid response, health system, compliance with international norms, and risk environment (Nuclear Threat Initiative, 2019[166]). However, not long after the declaration of a pandemic by WHO, it was recognised that GHSI rankings appeared to be negatively correlated with the success of a country's early response or positively correlated with fatality rates (Goldschmidt, 2022[165]). In general, this relationship had reversed itself by the end of 2021; however, there are various reasons why better prepared countries failed to respond more effectively in the early days of the pandemic. Critics emphasise that the index overlooks key context-specific dimensions of pandemic preparedness and response, including geography, the centralisation of government authority, political leadership, within country inequality, and social security provisions (Baum et al., 2021[167]). Other areas lacking attention reflect assumptions and biases inherent to the culture of science policy development in many high-income countries. Insufficient attention is given to the importance of participatory approaches and the involvement of civil society, as well as gaps between theoretical capacity, willingness to respond, and the application of actual capacity.

[9] The Netherlands utilised a novel approach, the Participatory Value Evaluation (PVE) to engage 30,000 citizens in providing guidance to the government regarding the relaxation of lockdown measures during the pandemic (Mouter, Hernandez and Itten, 2021[164]). Through a digital environment, citizens were provided with information related to the policy options being considered by the government, the concrete implications of each option, and constraints faced by the government. Individuals then provided a recommendation based on this information, which was used to rank policies in terms of their desirability using a behaviourally-informed choice model. Similarly, the novel Creating Our Future initiative, introduced by Science Foundation Ireland during the transition from the COVID-19 response to recovery, is meant to serve as a 'government-led national brainstorm' on future research priorities. The initiative involves a diversity of stakeholders, including the public, to curate innovation problems applicable to the local context and aligned with international grand challenges. Irish citizens were invited to submit their ideas to be reviewed and analysed in a process led by a multidisciplinary panel of experts.

[10] The Expert group on the economic and societal impact of research and innovation (ESIR) was created in 2017 by the European Commission to provide it with evidence-based policy advice regarding the development of future-focused and transformational policy. It represents a high-level group of experts that advises European and national policymakers on research and innovation, sustainability, policy experimentation, and solution-oriented initiatives for existing grand challenges. During the pandemic, the group produced several policy briefs and focus papers. For example, the first policy brief, "Protect, prepare, and transform Europe: Recovery and resilience post COVID-19", advocates for "resilience by design, not disaster" as a core dynamic of a co-ordinated European Union response to the pandemic (Dixson-Decleve et al., 2020, p. 2[127]).

Concluding Remarks and Policy Implications

The COVID-19 pandemic has been a disruptive, cascading global crisis, the likes of which national and international science systems have not been challenged with for many decades. In many ways, the response has underscored that science systems and science policy must continue to evolve to address novel challenges and meet new threats, but also to mitigate long-standing structural issues that limit effectiveness under normal conditions. In this regard, there are important opportunities for mutual learning and reflection across different jurisdictions and actors on what is needed from science to help societies prepare for, respond to, recover from, and adapt to crises.

This report represents one-third of the learnings gathered from an analysis of how national science systems were mobilised to respond to the pandemic. These learnings are at the 'meta-level' and aim to bridge lessons from the COVID-19 pandemic with the broader issues of resilience and sustainability transitions. This meta-analysis focuses on areas requiring action that are common to many, or all, of the six functional areas covered in the first reports: 1) Policy for science – access to data and information, research infrastructures, and science-industry collaborations; and 2) Science for policy and society – priority setting and co-ordination, scientific advice, and public communication and engagement.

Analysis has brought to the fore significant connections between different aspects of the scientific response, emphasising how interdependencies can contribute to or detract from effectiveness of the system as a whole. Factors that have enabled and challenged the mobilisation of science systems in response to the COVID-19 pandemic have revealed or emphasised key deficits in a number of inter-related areas. These common deficits can be considered in terms of the five 'meta-themes' proposed in this report: 1) Agile and strategic mobilisation capacity; 2) Managing conflicting priorities; 3) Co-ordination and collaboration across levels of governance; 4) Transdisciplinary and reflexive science; and 5) Dynamic and system-oriented governance.

The meta-themes are interconnected in that they enable, or are enabled by, issues and actions within other meta-themes. The structural nature of many of these issues and actions inherently imply a need for policymakers to move beyond the current the status quo. Novel approaches to policy are required to improve the resilience of science and societal systems in the face of ongoing and future crises and societal challenges. Fundamental to this transformation is the adoption of more **dynamic and system-oriented governance** processes and mechanisms. Changing what and who is prioritised at the strategic level is necessary but not sufficient to deliver systemic change. Transformation must go deeper, to reflect on, question, and adjust how policy itself is developed and the inputs, processes, and contributors that feed into this.

Dynamic governance can provide science policymakers with important insights to proactively develop the capabilities, mechanisms, and relationships required for the agile and **strategic mobilisation of science capacity** during crisis response. National efforts to respond to the COVID-19 pandemic have demonstrated the need for long-term investment into key elements of science systems – data and information, research infrastructures, and partnerships. In the same vein, activities that connect science to policy and society have also required and benefitted from the ability to leverage established science system elements. Fostering synergies, addressing duplication and gaps, and facilitating the evolution of technological and human capacity requires proactive and strategic action and investment; however, in many countries and internationally, budgetary challenges have limited the ability of policymakers to act pre-emptively or tactically.

When effectively connected to policy development processes, strategic foresight has enabled the translation of potential future needs and challenges into pre-emptive and timely investments and action. Foresight can improve the ability of policymakers to understand and prepare for potential futures and the impacts of crises and societal challenges which may shape these futures. In this context, it can be important also for assessing and leveraging technological advances and mitigating associated risks. In some jurisdictions, having mechanisms in place during the pandemic to enable the engagement of non-science policymakers and external actors, including community representatives, has been key to addressing demographic or context-specific needs or challenges and tailoring response efforts appropriately. These actors can also provide important long-term guidance on the shaping of science system capacities and priorities to improve resilience.

Perhaps most critical with regard to mobilising capacity is the concept of evaluation, which can provide policymakers with critical insight into the current capacity and constraints of science systems. In turn, this understanding can facilitate efforts to leverage, expand, or divert scientific capacity. Even more consequential is the role that evaluation and research assessment play in guiding the evolution of science systems and science policy. Current evaluation processes are largely dependent on traditional metrics (e.g., publications and intellectual property). The narrow use of these measures reinforces the siloed and fragmented organisation of many national science systems and policy landscapes. The emphasis on quantitative measures of short-term outputs is a factor in the increasing precarity of public research careers (particularly for early-career researchers and underrepresented demographics) and has a negative impact on the global advancement of Open Science agendas.

Tensions between conventional research evaluation practices and more recent science policy objectives, such as public engagement, inclusion, global preparedness, Open Science, and the generation of societal value underscore the need for science policymakers to engage with and **manage conflicting priorities** in the development and uptake of science. There are different dimensions to science and various points of convergence where actors from diverse countries, disciplines, sectors, and policy domains must interact. Limited resources require that science policy is developed to achieve a beneficial balance between competing interests, such as fundamental vs. applied research or nationally vs. globally oriented initiatives. Effective tools and guidelines are important to support policymakers and scientists in understanding, accommodating, or negotiating conflicting priorities, interests, and expectations in collaborative scientific activities. A culture that recognises the need to engage with and manage the tensions inherent to science activities provides an important foundation to ensure that during crises, holistic solutions can be developed swiftly and collaboratively. During the pandemic, effective co-ordination and collaboration has been necessary in multiple respects: across levels of governance (both internationally and domestically), across sectors and scientific disciplines, and across policy domains within national governments.

The global shock precipitated by the SARS-CoV-2 outbreak has exceeded the capabilities of any single country and has required effective co-ordination, **co-operation, and collaboration across levels of governance**. At the international scale, both previously established and new collaborations have contributed significantly to the COVID-19 pandemic response using a variety of mechanisms, from the communication and exchange of data, information, and expertise to agreements, frameworks, or even transnational agencies. At the same time, significant obstacles to international co-operation have persisted. Challenges posed by unnecessary bureaucracy, lack of interoperable standards and systems, cultural differences, and conflicting interests, ranging from national security concerns to political, economic, and commercial priorities, have constrained co-operation across borders, to the detriment of certain areas and countries.

While public health and social measures (PHSMs) often serve as a first line of defence in public health crises, international co-ordination has been noticeably lacking in relation to the use and adaptation of such measures. At the national level, rigorous scientific evaluation of PHSMs has been inhibited by several factors, including insufficient political will and rigid ethical requirements. It is also likely that national prestige and lucrative industry interests have concentrated global attention on the development and production of vaccines to the detriment of other interventions. At the same time, the pandemic has demonstrated that global crisis preparedness will require national governments, funders, industry partners, and intergovernmental agencies to improve inclusive and representative engagement of low- and middle-income countries (LMICs) in scientific activities. While efforts have been made over several decades to try to build the necessary capacity, for various reasons, the scale and nature of the investments has fallen short of what is needed. There is growing recognition that new approaches are needed to drive inclusive international science capacity building and research activities

The complexity and uncertainty of the pandemic has required the collaboration of diverse scientific disciplines, sectors, and policy domains to develop **transdisciplinary and reflexive science**-based solutions. Yet, as noted with regards to PHSMs, in the early days of the response, many governments failed to prioritise scientific advice and activities in the social sciences and humanities. The belated engagement of these fields has awakened old arguments about the hierarchy of scientific disciplines and it is likely that the incompleteness of the scientific evidence base used to inform policy has led to flawed policies in some instances. While the heavy focus on life and biomedical sciences, has produced significant and rapid advances in vaccines and diagnostics, impediments to their uptake and variability in the health outcomes of different demographics have emphasised the importance of social determinants of health and the need to consider and include disadvantaged population groups in the development of solutions.

Multidisciplinary data and broad collaborations, including partnerships with industry, government and civil society have been important to ensure that national efforts to respond to COVID-19 are aligned with and address local circumstances and need. In some economies, the active participation of the public has been a key dimension of response efforts to expedite the collection and use of sensitive data, challenge disciplinary assumptions, and foster societal trust. However, even under normal circumstances, integrating data, information, and expertise from diverse stakeholders and domains poses a significant challenge. Collaboration requires the navigation and negotiation of different, and potentially conflicting, motivations and expectations. The difficulty of this task grows with the diversity of the collaborators engaged and it is not surprising that previously established data sharing mechanisms and partnerships have played a key role in response efforts. It has also been important for tensions and conflicts, when they arise, to be explicitly acknowledged and unpacked, which has required scientists to embrace skills and approaches conducive to self-reflection and mediation.

During the COVID-19 pandemic response, different and, at times, experimental approaches have been adopted to reconcile conflicting priorities within partnerships and to engage new contributors, such as patient groups, in scientific activities. Likewise, the pandemic response has emphasised the need for science policymakers to be willing to deviate from conventional practices and draw on broad insights. Many aspects of the COVID-19 pandemic were unprecedented, volatile, and complex and required the development of provisional and adaptable initiatives. Efforts to rapidly mobilise national science systems in response to the crisis have emphasised the need for novel and experimental configurations of actors, institutions, and practices in the development of science policy. Many countries have been challenged by the extent of the intersections and linkages between different policy domains and the fragmentation which currently characterises the policy landscape. In this respect, the willingness and capacity of policymakers to experiment, fail, and learn will be crucial to the cultivation of resilience in science systems.

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Annexes

Annex 1: Alignment of meta-themes, areas for intervention and specific policy options

Meta-Theme: Agile and strategic mobilisation of capacity

Interventions for Resilience	Alignment with Policy Options for Policy for Science (Report 1) and Science for Policy and Society (Report 2)	
1. Take a systemic and long-term approach to science system investments to improve their ability to prepare for and respond to crises and build resilience.	DA 1.1.	Proactively allocate support required to develop infrastructures and tools for real-time data collection, management, and analysis across all relevant scientific domains
	DA 1.2.	Make additional strategic investments into institutional, disciplinary, sectoral, or national data infrastructures, taking into consideration economies of scale, flexibility, and resilience.
	RI 1.1.	Adopt systemic approach when making investment decisions to incentivise and promote the development of infrastructures, capacities, and the relationships required to address cross-cutting grand challenges and optimise resilience.
	RI 1.3.	Establish long-term agreements and secure funding commitments with national RIs to enable proactive integration of emergency response activities into their operations
	SIC 1.1.	Prioritise sustained action to develop and maintain strong and open networks and facilitate the development of underlying and enabling conditions. Credible and adequately resourced research institutions and infrastructures are important in addition to technological and human capacity, data sharing infrastructures, processes, and culture.
	SA 1.1.	Ensure that sustained, long-term and strategic investment into science is made to provide the evidence base needed to manage future pandemics and other crises.
2. Leverage and build on established capacities to improve the agility and adaptability of science systems when responding to crises.	RI 2.1.	Develop long-term strategies for development, attraction, retention of expertise, including scientific, management, and administrative capacity.
	RI 2.2.	The critical roles played by RIs in training, education and public engagement must be reflected in their mandates and funding allocations.
	RI 2.3.	Advance partnerships with public and private sector research providers to facilitate training and labour mobility and increase connectivity of science systems.
	RI 3.2.	The proactive integration of digital and other enabling innovations into the operations of RIs should be encouraged and supported. This is key to ensuring sustained collaboration, security, and resilience and will require specific training and resources.
	RI 3.3.	RIs must develop governance and technological solutions to streamline flexible, secure, and accelerated remote access to data and other assets, while addressing corresponding challenges (cybersecurity and network vulnerability).
	RI 3.4.	Invest in and support tools and infrastructures, such as digital platforms to increase the visibility and awareness of RIs with potential users.
3. Re-design science programming and	RI 1.5.	Prepare RIs to contribute to crisis response by supporting activities outside of set mandates. This will require established decision-making and approval mechanisms, capacity, and governance

funding processes, to facilitate the expedited and agile mobilisation of existing and new resources as required during crises.		frameworks to expedite the adaptation of operational priorities to accommodate new demands.
	PSC 1.1.	Ensure that science actors have the autonomy to set the research agenda during early stages of crisis response and the necessary strategic intelligence and capacity to anticipate the information needs of policymakers.
	PSC 1.2.	Facilitate flexible and agile agenda setting to foster preparedness and accelerate reassessment and reallocation of priorities and resources based on urgency and impact.
	SA 1.2.	Involve the scientific community in long-term emergency preparedness activities to facilitate rapid mobilisation during crises and ensure alignment between advice, policy needs, and crisis management processes.
	SA 1.3.	Proactively establish mechanisms to ensure existing capacities can be rapidly leveraged and adapted as necessary and scientific institutions are prepared and supported to effectively respond to crises.

Meta-Theme: Managing conflicting priorities

Interventions for Resilience	**Alignment with Policy Options for Policy for Science (Report 1) and Science for Policy and Society (Report 2)**	
1. Recognise and address tensions between national priorities and global need regarding the development and deployment of scientific capacity to ensure global preparedness and resilience.	DA 3.1.	Catalyse joint international partnerships and investments in LMICs to develop and strengthen infrastructures and local scientific capacities, including for the management and use of FAIR data.
	DA 3.2.	Support established and emerging initiatives in LMICs to develop and host data assets and encourage international networking of repositories to provide equitable access to globally inclusive data assets.
	DA 3.3.	Include and ensure that representatives from LMICs have a voice in international efforts to advance the adoption of Open Science policies globally.
	RI 5.3.	Invest in high-priority regional infrastructures critical to the abilities of LMICs to respond effectively to future crises and complex societal challenges. In some instances, private funding or industry partnerships can potentially be leveraged to achieve this.
	SIC 3.2.	Governments and funders have a role to play in engaging industry in developing elements of science systems and science activities for policy and society in LMICs.
	PSC 3.2.	Ensure that global research agendas are inclusive of the needs and challenges of disproportionately affected regions and populations. Where required, jurisdictions should be supported, potentially via regional intermediaries, to translate global priorities to the local context.
	SA 3.3.	Invest in the long-term development of science and science advice capacities in the Global South and ensure that international science advice and policy development is representative of the challenges, concerns, and opportunities occurring across all countries.
2. Maintain dedicated support for a diverse portfolio of science activities focused on solutions for socio-economic challenges as well as the	DA 5.2.	Funders should facilitate and incentivise the creation and sharing of datasets as an outcome of funded research. Evaluation structures should also be adapted to appropriately acknowledge novel and curated datasets as first-class research outputs and recognise the contributions of data creators and stewards.
	DA 5.3.	Incentivise researchers to make publications and underlying data (including software and study design) from publicly funded research projects openly accessible. Open access policies can be used to mandate or encourage the submission of academic papers and data to open access journals and data repositories.

advancement of science.	SIC 3.2.	Prioritise high-risk science activities with limited short-term economic returns, but significant potential for the generation of societal value. Policy action will be important to incentivising mission-driven science-industry partnerships at national, regional, and international levels, while long-term, sustained support for fundamental science activities will be important to enable science actors to engage with industry in future collaborations.
	SIC 3.3.	Novel business models and funding approaches are required to balance conflicts between commercial, academic, and societal priorities in science-industry collaborations. Different approaches to IP and the ownership of research outcomes, including modular and flexible arrangements, should be incentivised or encouraged by policymakers and funders.
	PSC 2.2.	Support a diverse suite of research initiatives in periods between crises and during crisis response to balance existing and new research priorities and short-term returns – prestige and financial returns – and long-term benefits – the generation of societal value and resilience.
3. Systematically and proactively address ethical, legal, and social barriers to scientific studies and data collection, while honouring established standards and regulation.	DA 6.1.	Promote the universal adoption of informed consent procedures and sharing agreements that enable ethical downstream sharing, reuse, and preservation of data. Particular attention must be paid to the acquisition, development, and reuse of social sciences data.
	DA 6.2.	The adoption of extraordinary measures for data collection and analysis during crisis response must maintain full transparency and accountability, including clear parameters for reversal. A diversity of stakeholders should be engaged ex ante to ensure that actions are warranted, proportionate, and consistent with societal values.
	DA 6.4.	Promote the use of federated safe computing environments to link large health datasets, whilst maintaining personal privacy and security. Data repositories should be supported in testing and adopting novel technical innovations and approaches to protect sensitive data and mitigate risks posed by cyberattacks.
	DA 6.5.	Promote or mandate the use of certified trustworthy data repositories. Methodologies to ensure long-term data preservation, rigorous governance, and accountable use should be developed transparently in collaboration with a diverse group of stakeholders, including repository users, policymakers, and civil society representatives.
	PSC 2.4.	Proactively address knowledge gaps in the development and implementation of PHSMs to optimise their use during crisis response. Proactive action is required to conduct rigorous randomised control trials and establish baseline data on effectiveness before the next crisis.
4. Advance mutual understanding, improve trust and reflexive engagement between scientists, policy makers and the public.	DA 2.4.	Implement and support long-term science and data literacy training through the established education system and ad hoc programming targeted to specific population groups, e.g., seniors, prisoners, migrants, and other stakeholders, such as policymakers and elected officials.
	DA 5.4.	Access to important research results should be accelerated through a variety of avenues. Institutions and publishers can be incentivised to develop expedited, transparent, and trusted peer-review processes and capacity. Use of preprint platforms should also be encouraged to make preliminary outcomes openly accessible. However, safeguards, such as making supporting data available in conjunction with preprints, are important to mitigate against misuse.
	SA 4.1.	Integrate formal and transparent governance mechanisms into science advice structures to ensure their legitimacy and independence.
	SA 4.2.	Embed quality assurance processes into science advice structures that ensure that scientific evidence is robust, reliable, and aligns with ethical standards.
	SA 4.3.	Clearly and transparently distinguish roles of experts and policymakers in the development and use of science advice, and protect the independence and autonomy of science, recognising that its translation into policy is an inherently normative and political process.
	SA 4.4.	Clarify and codify legal liabilities of advisors, while establishing mechanisms to mitigate politicisation of science and protect experts from verbal and physical abuse.
	PCE	Engage directly with the public using a variety of communication mediums and experimental

	1.2.	approaches to address distinct aspects of the crisis response.
	PCE 1.3.	Engage the social sciences and humanities in crisis response efforts to utilise qualitative and quantitative data, including narratives and social and behavioural insights. This is important to ensure that both policy interventions and communication strategies are appropriate and effectively targeted to the cultural context.
	PCE 2.1.	Crisis communication must be transparent about uncertainties in the science being used to inform policy decisions. Openness and engaging a diversity of perspectives is particularly important in rapidly evolving situations which may require changing policy approaches.
	PCE 2.2.	Improve science, data, and digital literacy to ensure that the public is familiar with the scientific process and what constitutes scientific evidence, able to engage effectively with science, and able to identify and appropriately address mis- and disinformation.
	PCE 2.3.	Approach communication efforts during crises with nuance and focus on how words, tone, and gestures might be interpreted by different groups and in different contexts. It is also important to actively address the circulation of misinformation through approaches that avoid creating or exacerbating conflict or entrenched perspectives.

Meta-Theme: Co-ordination and collaboration across levels of governance

Interventions for Resilience	Alignment with Policy Options for Policy for Science (Report 1) and Science for Policy and Society (Report 2)	
1. National governments must recognise and support efforts made by international agencies to foster co-ordination, alignment, and collaboration, to improve global preparedness and resilience.	PSC 3.1.	Improve collaboration and communication between international agencies and regional or domestic bodies to co-ordinate cross-country research priorities and address the entire crisis management cycle.
	SA 3.2.	Prioritise the use of established international agencies and collaboration channels to inform development of (universally relevant) science advice and facilitate dissemination and adoption of good practices across countries.
2. Prioritise the development and maintenance of multilateral collaborations and international platforms to improve the visibility, alignment, and co-ordination of national science activities and assets.	DA 4.2.	Broad and inclusive collaborations should leverage and build on established national and international efforts to develop, test, and advance Open Science and data sharing policies and resources. These initiatives should also engage and support relevant stakeholders in co-ordinating and harmonising activities across jurisdictions and expanding global participation.
	DA 5.1.	Registration of publicly funded clinical studies in international trial registries and the open sharing of study protocols, should be mandated to reduce duplication and improve trial design.
	RI 1.4.	Designate selected RIs as national or regional crisis response centres to be supported by policymakers and funders in co-ordinating the crisis response activities of disparate infrastructures and supporting the strategic mobilisation of national science capacities.
	RI 5.1.	International agencies and national governments must support co-operative mechanisms, such as international vaccine platforms, to facilitate and accelerate the development of co-ordinated, collaborative research.
	R1 5.2.	Governments and funders in OECD countries should consider broadening the mandates of national RIs and provide support for them to actively participate in international networks and support international organisations as appropriate.
3. Co-ordinate, align, and connect science	SIC 1.3.	Funding agencies should experiment with the development of new funding models and co-ordinating joint funding programmes with other national and cross-border agencies.

programming across national and subnational levels of governance.	PSC 1.3.	Nurture long-term collaboration between and among policymakers, scientists and other actors to ensure that national STI activities are co-ordinated across different agencies and levels of government.
	SA 3.1.	Improve co-ordination and communication between sub-national and national-level science advisory structures, ensuring clarity regarding divisions of responsibilities and remits. This is of particular importance in federalist jurisdictions and where there are significant economic and social disparities across territories, which need to be reflected in policy.

Meta-Theme: Transdisciplinary and reflexive science

Interventions for Resilience	Alignment with Policy Options for Policy for Science (Report 1) and Science for Policy and Society (Report 2)	
1. Ensure that researchers have the tools, skills, and resources to collect and synthesise multivariate and multidisciplinary data into transdisciplinary and context-specific knowledge.	DA 4.1.	Facilitate the adoption of Open Science practices across scientific disciplines by tailoring levels of support and guidance to the needs of different disciplines.
	DA 4.3.	Support connectivity and co-ordination between owners and users of related research outputs (e.g., peer-reviewed literature and preprints, datasets, and software) using tools, such as standardised, cross-disciplinary data dictionaries and digital communication platforms.
	DA 4.4.	Raise the visibility of open data and knowledge resources and facilitate and incentivise the stewardship, integration, and reuse of data to address targeted challenges. Established instruments, such as data sharing or material transfer agreements can be used to connect data repositories and other data holders.
	DA 4.5.	Data repositories and other data providers should drive the testing and adoption of enabling technology to facilitate and expedite the curation, recombination, and meta-analysis of existing knowledge (e.g., machine-readable formats, linking to preregistration or open-source repositories, high-powered computing infrastructures, and artificial intelligence).
	DA 5.4.	Access to important research results should be accelerated through a variety of avenues. Institutions and publishers can be incentivised to develop expedited, transparent, and trusted peer-review processes and capacity. Use of preprint platforms should also be encouraged to make preliminary outcomes openly accessible. However, safeguards, such as making supporting data available in conjunction with preprints, are important to mitigate against misuse.
	DA 6.3.	Proactively engage with private sector actors with robust data or analytical resources and leverage these connections during crisis response.
	SA 2.2.	Prioritise the development of the culture, skills, and methods required to synthesise insights from across different disciplines, geographies, and sectors in the development of science advice. In some situations, the integration of diverse inputs may benefit from, or require, guidance from designated and experienced champions.
2. Balance swift action with the solicitation and integration of diverse insights from across sectors and domains to ensure that scientific insights and solutions are broadly informed and targeted.	DA 4.4.	Innovative policy tools, such as competitions and hackathons can also be deployed to engage a diversity of stakeholders on targeted issues.
	RI 4.1.	Interdisciplinary RI clusters and cross-infrastructural workflows can be used to reduce administrative and legal barriers and improve interoperability across infrastructures. They are also important for improving co-ordination across scientific disciplines and enabling broad and inclusive collaborations, e.g., for advancing a global One-Health approach.
	RI 4.2.	Physical and e-infrastructures should be empowered as collaboration switchboards tasked with engaging actors from across disciplines, sectors, and geographies and supporting them to develop joint research activities.
	RI 4.3.	Encourage and incentivise RIs to engage industrial users and build trusted relationships.

	SIC 2.2.	Use intermediaries, digital platforms, and other collaboration mechanisms to engage partners in a targeted and strategic way and support the development of communication and trust between academia and the private-sector
	SIC 3.3.	Novel business models and funding approaches are required to balance conflicts between commercial, academic, and societal priorities in science-industry collaborations. Different approaches to IP and the ownership of research outcomes, including modular and flexible arrangements, should be incentivised or encouraged.
	PSC 2.3.	Prioritise cross-disciplinary collaboration and mission-oriented research to facilitate the development of comprehensive and interdisciplinary solutions.
	SA 2.1.	Include and prioritise a diversity of appropriate expertise in science advice structures. Where a diversity of perspectives is obtained from multiple advisory groups, it is important that mechanisms are developed and tested in advance to ensure co-ordination, synthesis, and translation of multiple scientific inputs into policy processes.
	PCE 3.1.	Invest in establishing the infrastructure, capacity, resources, and culture required to advance and adapt public engagement mechanisms that align with specific and changing contexts.
3. Prioritise the inclusive representation and engagement of disadvantaged and underrepresented populations in science activities by institutionalising EDI as a fixed priority of funding and evaluation frameworks.	DA 2.1.	Proactively fund science activities to address deficiencies in the availability of data disaggregated by age, race, and sex during respites between crises so that the tools, rules, and processes are in place for crisis response.
	DA 2.2.	Develop mechanisms, tools, and skills to incentivise and support the engagement of community groups, patients, and citizens in data science activities, from co-design of projects to public-led citizen science initiatives.
	DA 2.3.	Mandate or encourage the adoption of principles that promote the representation and engagement of ‘neglected’ population groups in the development of research and the collection, stewardship, and governance of associated data e.g., the CARE principles.
	SIC 3.2.	Ensure that science-industry partnerships are incentivised to integrate a diversity of perspectives and prioritise the needs of different population groups, including disadvantaged populations.
	PCE 3.2.	Encourage and actively seek the participation of under-represented, disadvantaged, and divergent perspectives through the development of partnerships and forums that can facilitate safe and open dialogue. Engagement with representatives and community leaders from these groups can also help to counter misinformation.
	PCE 3.3.	Encourage and support bottom-up citizen science activities, particularly those that do not align with the status quo or dominant political agendas, through political and financial means.

Meta-Theme: Dynamic and system-oriented governance

Interventions for Resilience	Alignment with Policy Options for Policy for Science (Report 1) and Science for Policy and Society (Report 2)	
1. Invest in fostering and connecting foresight capacities to policy development processes to enable the conversion of potential future challenges, needs, and opportunities into current actions.	PSC 1.3.	Joint participation in strategic foresight and crisis preparedness exercises is important to improve agility and resilience.
	PSC 2.1.	Adopt an all-hazards methodology to surveillance and long-term agenda setting to improve the preparedness of science systems to respond to crises.
2. Invest in the infrastructure, skills, and tools required to evaluate policy and other	SA 3.2.	Prioritise the use of established international agencies and collaboration channels to inform the development of universally relevant science advice and facilitate the dissemination and adoption of good practices across countries

initiatives and facilitate the integration and dissemination of learnings and good practice to improve the development and adaptation of policy across borders.	PSC 3.4.	Leverage learnings and good practice from across countries, disciplines, and sectors to improve the design, evaluation, and adaptation of PHSMs.
3. Improve the translation of high-level objectives into practical and effective policy decisions by encouraging self-reflection, experimentation, and broader participation in the development and implementation of science policy.	RI 1.2.	Engage relevant research infrastructures and user communities in developing strategy and policy for addressing crises and complex societal challenges. This will allow for the creation of initiatives and resources that are modern, effective, user-friendly, and integrated into the broader system.
	SIC 1.2.	Awareness and evaluation of the existing policy mix will be important to support policymakers in understanding potential positive or negative interactions when designing new initiatives.
	SIC 2.1.	Engage industry stakeholders proactively in governance functions and in the development of initiatives to strengthen long-term trust and social capital.
	SIC 3.5.	It is important that science programming and bureaucracy do not impede the ability of actors to develop innovative and experimental ways of working. Policymakers should leverage context-dependent insights and guidance from a diversity of stakeholders to ensure the relevance, effectiveness, and agility of policy.
4. Take a whole-of-government approach when addressing complex crises and other societal challenges to ensure that approaches taken to prepare and respond are coherent, holistic, and, where needed, catalyse structural transformation.	PSC 1.4.	Integrate and embed scientific evidence into policy development processes and social and policy imperatives into the scientific research agenda to support long-term preparedness, agility, and resilience.
	SA 2.3.	Ensure that science advisory processes at different geographic scales are fully adapted to their particular context and reflect the history, culture, regulatory and administrative regimes in which they operate.

Note: DA= Data and information access, RI= Research Infrastructures, SIC= Science-industry collaboration, PSC=Priority setting and collaboration, SA= Scientific Advice, PCE=Public communication and engagement. Numbering denotes report and chapter, e.g. 2.3 refers to report 2 chapter 3.

Annex 2: Expert Group Membership

Country	Name	Position	Organisation
AUS	Julian Thomas	Director, Professor of Media and Communications	Swinburen Institute for Social Research
BEL	Marie Delnord	Public Health Researcher, Epidemiologist	Sciensano, Belgian Public Health Institute
CAN	David Castle	Researcher in Residence	Office of the Chief Science Advisor, Government of Canada
CZE	Petr Bartůněk	Group Leader	Institute of Molecular Genetics,Czech Academy of Sciences
CZE	Tereza Stöckelová	Researcher, Associate Professor of General Anthropology	Institute of Sociology of the Czech Academy of Sciences
FRA	Yazdan Yazdanpanah	Director	ANRS Maladies Infectieuses Emergentes
JPN	ARIMOTO Tateo	Principal Fellow	Center for Research and Development Strategy (CRDS) and Japan Science and Technology Agency (JST)
JPN	Mr. OYAMADA Kazuhito	Fellow	CRDS and JST
JPN	Mr. KANO Hiroyuki	Fellow	CRDS and JST
KOR	Dr. Inkyoung SUN	Head, Office of Development Cooperation Research	Science and Technology Policy Institute (STEPI)
KOR	Myong Hwa Lee, Ph.D	Head, Office of National R&D Research	Science and Technology Policy Institute (STEPI)
NLD	Prof. dr. F.W.A. (Frans) Brom	Professor, Normativity of Scientific Policy Advice	Ethics Institute, Utrecht University
NOR	Trygve Ottersen	Executive Director	Norwegian Institute of Public Health
PRT	Vanda Oliveira		FCT
PRT	Isabel Carvalho-Oliveira	Delegate and NCP for Health in the Horizon Europe Programme	Agency for Clinical Research and Biomedical Innovation
ZAF	Dr Ntsane Moleleki	Senior Specialist – Policy Investigation	National Advisory Council on Innovation (NACI)
ZAF	Dr Tozama Qwebani-Ogunleye	Project Manager	Institute of Traditional Knowledge, Vaal University of Technology (VUT)
UK	Randolph Kent	Director	Humanitarian Futures
UK	Mike Bright	Deputy Director, International	UK Research and Innovation

Annex 3: International Workshop Series Overview

	Workshop	Description
R2: POLICY FOR SCIENCE	**I. 23 April 2021:** Enhancing access to research data during crises	**Completed in partnership with the RDA and co-located with RDA's 17th Plenary meeting.** Sessions focused on high-level policy frameworks and domain-specific issues. Biomedical and clinical data, omics and epidemiology, and social sciences and interdisciplinary research were covered in individual sessions.
	II. 11 May 2021: Mobilising research infrastructures in response to COVID-19	**Completed in partnership with Science Europe and held as a satellite event of the 2021 International Conference on Research Infrastructures (ICRI).** Sessions explored key challenges and good practices for the emergency management and operation of research infrastructures across different research domains. Actions to enable preparedness for future crises were also considered.
	III. 16 September 2021: Improving academia-private sector interactions	**Completed in partnership with the OECD working party on Technology and Innovation Policy (TIP).** Actors directly involved in participating and/or funding transdisciplinary research or co-designed policy presented learnings from specific case studies. GSF and TIP Bureau members also provided short interventions reflecting workshop learnings and their national contexts.
R3: SCIENCE FOR POLICY & SOCIETY	**IV. 4-5 October 2021:** Priority setting and co-ordination of research agendas	Case study presentations and moderated discussion covered setting, steering, and co-ordinating research priorities during crises. Specific focus was placed on data collection, evidence for public health and social measures, and maintaining agility and flexibility. In a final panel discussion, participants reflected on the importance of international co-operation and global and national preparedness for future crises.
	V. 3-4 March 2022: Scientific advice in crises	A diversity of scientific disciplines was represented by key experts in scientific advisory processes and policy development. Critical issues included interplays between science, policy, and politics; transdisciplinary knowledge; public communication and trust; co-ordination across governance levels; and implications for future crisis response.
	VI. 22 April 2022: Public communication and engagement in science	The final event was added to expand on insights developed in earlier workshops regarding the role of civil society in a science-based response to crisis. Sessions were designed around the mitigation of mis- and disinformation; managing and communicating uncertainty; public engagement; and long-term trust. In a final panel discussion, participants reflected on the importance of advancing novel participatory approaches, while ensuring feasibility and buy-in from civilians, as well as policy and science actors.

Annex 4: Workshop Presenters and Panellists

Workshop Session	Name and Title	Organisation	Country
Enhancing access to research data during crises			
Basic medical and clinical research	Nevine Zariffa, Scientific Project Lead	International COVID-19 Data Alliance (ICODA)	UK
	Michael Brudno, Chief Data Scientist	University Health Network	CAN
	Marie Paule Kieny, Director of Research	Inserm	FRA
Omics research and epidemiology	Niklas Blomberg, Director	ELIXIR	EU
	Priyanka Pillai, Academic Specialist in Bioinformatics	University of Melbourne	AUS
	Dr. Xihong Lin, Professor of Biostatistics; Co-ordinating Director of the Quantitative Genomics Program	Harvard and MIT	USA
Social sciences and interdisciplinary research	Stefania Milan, Associate Professor of New Media and Digital Culture	University of Amsterdam	NLD
	Dr. Katja Mayer, Senior Postdoctoral Fellow of Science and Technology Studies	University of Vienna	AUT
	Dr. Yukio Ohsawa, Professor	University of Tokyo	JPN
National and international policy perspectives	Camilla Stoltenberg, Director General	Norwegian Institute of Public Health (NIPH)	NOR
	Kazuhiro Hayashi, Director of Research Unit for Data Application	National Institute of Science and Technology Policy (NISTEP)	JPN
	Yazdan Yazdanpanah, Director	ANRS Maladies Infectieuses Emergentes	FRA
	Dr. Claudia Bauzer Medeiros, Professor of Databases	University of Campinas and FAPESP	BRA
	Michael Kahn, Policy Analyst and Evaluator of STI	Stellenbosch University	ZAF
	Dr. Kiwon Jang, Senior Researcher	Korea Research Institute of Bioscience and Biotechnology	KOR
	Steven Kern, Deputy Director of Quantitative Sciences	Bill & Melinda Gates Foundation	USA
	Konstantinos Repanas, Policy Officer, Open Science Unit	European Commission	EU
Mobilising research infrastructures in response to COVID-19			
Adapting RI processes in emergency situations	Christos Arvaniditis, CEO	Lifewatch-ERIC	EU
	Philip Gribbon, Head of Discovery Research	Fraunhofer and EU-Openscreen	EU
	Dr. Makoto Tsubokura, Professor of Computational Fluid Dynamics	RIKEN Center for Computational Science and Kobe University	JPN
Preparedness and response of life science and health RIs	Dr. Michaela Mayrhofer, Head of ELSI Services and Research	ELSI-BBMRI	AUT
	Volker Gerdts, CEO	VIDO-INTERVAC	CAN
	Bryan Charleston, Director	Pirbright Institute	UK
Policy lessons learned and the potential role of research	Martin Taylor, Executive Director	Canadian Research Data Center Network	CAN
	Yazdan Yazdanpanah, Director	ANRS Maladies Infectieuses Emergentes	FRA
	Antonio Zoccoli, President	Istituto Nazionale Fisica Nucleare (INFN)	ITA
	Lukas Levak, Director	Ministry of Education	CZE
Improving academia-private sector interactions			
Challenges and good practices in co-creation during the crisis	Frank von Delft, Professor of structural chemical biology	University of Oxford	UK
	Kathryn Funk, Program Manager of PubMed Central	National Institutes of Health (NIH)	USA
	Jerry Sheehan, Deputy Director	National Library of Medicine – National Institutes of Health	USA
	Kirsimarja Blomqvist, Professor of knowledge management	LUT University	FIN
	Catalina Lopez-Correa, CSO	Genome Canada	CAN
	Hande Alpaslan, Head	TUBITAK, STI Policies Department	TUR

	Duygu Saracoglu, Senior Policy Expert	TUBITAK, STI Policies Department	TUR
Policy tools and instruments	Mark Ferguson, Director General	Science Foundation Ireland (SFI)	IRL
	Myong Hwa Lee, Head of the Office of National R&D Research	Science and Technology Policy Institute (STEPI)	KOR
	Tateo Arimoto, Visiting Professor of STI Policy	National Graduate Institute of Policy Studies (GRIPS)	JPN
	Kazuhito Oyamada, Fellow	Center for Research and Development Strategy (CRDS)	JPN
	Marnix Surgeon, Deputy Head	European Commission, Common Mission and Partnerships Service	EU
	Catarina Resende Oliveira, President	Agência De Investigação Clínica E Inovação Biomédica (AICB)	PRT
Key Takeaways	Catherine Ewart, Associate Director, International	UK Research and Innovation (UKRI), Science and Technology Facilities Council	UK
	Goran Marklund, Deputy Director General *Chair, TIP Working Party*	Vinnova	SWE
	Tiago Santos Pereira, Principal Researcher *Vice Chair, TIP Working Party*	Conselho Económico e Social (CES)	PRT
	Jerry Sheehan *Vice Chair, TIP Working Party*	Office of Science and Technology Policy (OSTP)	USA
	Kimikazu Iwase, Principal Fellow	Center for Research and Development Strategy (CRDS)	JPN
	Kai Husso *Vice Chair, TIP Working Party*	Ministry of Economic Affairs and Employment	FIN
Priority setting and co-ordination of research agendas			
Priority setting for research and data collection in the early crisis phase	Steven Hoffman, Scientific Director	Canadian Institutes of Health Research (CIHR)	CAN
	Virginia Murray, Head of Global Disaster Risk Reduction	UK Health Security Agency (UKHSA)	UK
	Charles Wiysonge, Director	Cochrane, South Africa and African Medical Research Council	ZAF
	Gregory Armstrong, Director of the Advanced Molecular Detection Programme	Centers for Disease Control and Prevention (CDC)	USA
Development of the evidence-base for social interventions	Atle Fretheim, Research Director	Norwegian Institute of Public Health (NIPH)	NOR
	Jan Brauner, PhD candidate in the Centre for Doctoral Training on Intelligent and Autonomous Machines and Systems	University of Oxford	UK
	Gideon Meyerowitz-Katz, Epidemiologist	University of Wollongong, School of Health and Society	AUS
	Susan Michie, Advisor to British Government	SAGE Advisory Group	UK
Priority setting and co-ordination as a crisis evolves	Balthazar Nunes,	Portugal National Institute of Public Health	PRT
	Camilla Stoltenberg, Director General	Norwegian Institute of Public Health	NOR
	Joseph Wu, Professor in public health	University of Hong Kong, China	HKG
	Byeongwon Park, Research Fellow	Science and Technology Policy Institute	KOR
International co-operation and priority setting: improving preparedness for the next crisis	Boitumelo Semete-Makokotlela, CEO	South African Health Product Regulatory Authority	ZAF
	Devi Sridhar, Professor of Global Public Health and Advisor to the Scottish Government on COVID-19	University of Edinburgh	UK
	Yazdan Yazdanpanah, Director	ANRS Maladies Infectieuses Emergentes	FRA
	Osamu Aruga, Director for International Affairs	Cabinet Office, Secretariat of STI Policy	JPN
	Ezekiel Emanuel, Vice-Provost and former government advisor on COVID-19	University of Pennsylvania	USA
Scientific advice in crises			
Science, policy and politics	Sheila Jasanoff, Pforzheimer Professor in science and technology studies	Harvard Kennedy School	USA
The operational	Sir Ian Diamond, Chief Executive	UK Statistics Authority	UK

challenges of making evidence-based policy	Jet Bussemaker, Chair and Professor	Council of Public Health and Society and Leiden University	NLD
	Bob Kolasky, Director of the National Risk Management Center *Chair of the OECD High-level Risk Forum*	United States Department of Homeland Security, Cyber and Infrastructure Security Agency	USA
Evolving advisory processes, roles and responsibilities of scientific advisors	So Young Kim, Director of the Korea Policy Center for the Fourth Industrial Revolution	Korea Advanced Institute of Science and Technology (KAIST)	KOR
	Marion Koopmans, Head of Viroscience	Erasmus University	NLD
	Petr Smejkal, Chief Epidemiologist	IKEM	CZE
	Dominique Costagliola, Senior Researcher and Deputy-Head	INSERM and Institut Pierre Louis d'Epidémiologie et de Santé Publique	FRA
	Patrick Fafard, Senior Investigator	University of Ottawa, Global Strategy Lab	CAN
Ensuring a holistic/ multidisciplinary evidence base	Muto Kaori, Professor of public policy	University of Tokyo, Institute of Medical Science	JPN
	Marijn de Bruin, Head of Research for Behavioural medicine	National Institute of Public Health and Environment	NLD
	Geoff Mulgan, Professor in social innovation and public policy	University College London	UK
	Rémi Quirion, President and Chief Science Advisor of Québec	International Network for Government Science Advice (INGSA)	CAN
	Bob Kolasky, Director of the National Risk Management Center *Chair of the OECD High-level Risk Forum*	United States Department of Homeland Security, Cyber and Infrastructure Security Agency	USA
Communication of scientific advice, building trust	Mikihito Tanaka, Professor in political science and economics	Waseda University	JPN
	Michael Bang Petersen, Professor in political science	Aarhus University	DNK
	Camilla Stoltenberg, Director General	Norwegian Institute of Public Health (NIPH)	NOR
	Dr. Henrique Barros, President	University of Porto, Institute of Public Health	PRT
Scientific advice at different scales: co-ordination and contextualisation	Melanie Davern, Associate Professor and Director	RMIT University and Australian Urban Observatory	AUS
	Christian Léonard, Strategic Director of Sciensano	Belgian Public Health Institute	BEL
	David Nabarro, Strategic Director; *former WHO Director and former UN special envoy on pandemics*	4SD	UK
	Nicole Grobert, Chair	European Commission Scientific Advisory Mechanism	EC
	Sir Ian Diamond, Chief Executive	UK Statistics Authority	UK
Implications for science advice in future crises	John-Arne Røttingen, Ambassador for global health	Ministry of Foreign Affairs	NOR
	Kiyoshi Kurokawa, emeritus Professor	University of Tokyo	JPN
	Helena Pereira, President of the Board of Directors	Fundação para a Ciência e a Tecnologia (FCT)	PRT
	Daan Du Toit, Deputy Director-General of International Cooperation and Resources	Department of Science and Technology	ZAF
	Rebecca Bunnell, Chief Science Officer and Director	Centre for Disease Control and Prevention (CDC), Office of Science	USA
Public communication and engagement in science			
Scientific information, disinformation, and misinformation: perspectives from communication professionals	Lu'chen Foster, Head of health partnerships	Facebook	USA
	Takahiro Kinoshita, Deputy-Chair	Covid-19 Navigator Cov-Navi	JPN
	Dr. Gabriela Capurro, Professor of Journalism and Communication	Carleton University	CAN
Managing diverse scientific opinions and uncertainties	Dr, Anat Gesser-Edelsburg, Head of the Health Promotion Program	University of Haifa, School of Public Health	ISR
	Jean-Gabriel Ganascia, Chairman and Professor of computer science	CNRS ethics committee and Sorbonne University	FRA

	Tracy Vaillancourt, Chair of the taskforce on COVID-19	Royal Society of Canada	CAN
Public engagement and mobilisation in science and science advice during crises	Li-Yin Liu, Visting assistant professor in Public Administration	University of Dayton	USA/TPE
	Felicity Callard, Professor in human geography	University of Glasgow	UK
	Dr. Barbara Prainsack, Professor in political science	University of Vienna	AUT
Building confidence and long-term trust	Takahiro Kinoshita, Deputy-Chair	Covid-19 Navigator Cov-Navi	JPN
	Li-Yin Liu, Visting assistant professor in Public Administration	University of Dayton	USA/TPE
	Felicity Callard, Professor in human geography	University of Glasgow	UK