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AGENDA FOR TRANSFORMATIVE SCIENCE, TECHNOLOGY, AND INNOVATION POLICIES

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OECD Agenda for Transformative Science, Technology and Innovation Policies

Multiple crises are triggering turbulence, instability and insecurity in contemporary societies, with impacts on economies, the environment, politics, and global affairs. An effective response will require governments to be more ambitious and act with greater urgency in their science, technology and innovation (STI) policies to meet global challenges. Sustained investments and greater directionality in research and innovation activities are needed, and these should coincide with a reappraisal of STI systems and STI policies to ensure they are "fit-for-purpose" to contribute to transformative change agendas. This policy paper provides a framework to support governments in making these assessments. It identifies six STI policy orientations for transformative change that should guide these assessments. It applies these orientations across multiple areas of STI policy, including R&D funding, the research and innovation workforce, and international R&D co-operation, and outlines a series of concrete actions policymakers can take to accelerate transformative change.

Keywords: Crisis Management, Policy Innovation, Research Directionality, System Reappraisal, Transformative Framework, R&D Cooperation, Accelerated Change, Funding Strategies.

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Reader's Guide

The *OECD Agenda for Transformative Science, Technology and Innovation (STI) Policy* (hereafter, the Transformative Agenda) provides high-level guidance for national STI policymakers in formulating and implementing reforms to support the acceleration and scale-up of positive economic and societal transformations in the face of mounting global challenges. Many of the points raised by the Transformative Agenda may also be of relevance to the work of a broad set of other stakeholders working in areas that can interact with STI activities in different ways. There are multiple points of entry and different key messages that readers might apply based on their roles and responsibilities in STI and STI policy systems.

- **High-level decision-makers** may take the most value from the introductory section, which details how and why socio-economic systems should transform, how STI can contribute to this, and the parallel need to transform STI and STI policy systems.
- For **STI policymakers**, the most applicable insights can be found in the sections covering specific policy areas, such as research and technology infrastructures or international STI relations. Key messages in these sections may also be useful for **stakeholders who are active in sub-national, national and international STI systems**. This includes researchers in the natural and social sciences, international and/or intergovernmental organisations, public research organisations, and industry, as well as entrepreneurs, civil society organisations, and citizens.
- The Transformative Agenda is also valuable for **policymakers working in other policy domains**, whether these are sector-specific (e.g., energy, agriculture, transportation) or horizontal (e.g., education, trade and investment). Many of the sections covering specific STI policy areas underline the importance of cross-government coherence and co-ordination. These sections may offer useful lessons on when, how and why sector-specific and horizontal policy domains should engage more actively with the STI policy domain.
- **The Transformative Agenda also aligns with and builds on the work of STI policy researchers and practitioners**. Key messages will depend on areas of focus; however, relevant insights are likely to be found in the sections outlining different policy orientations to help steer STI policy towards transformative change. In addition, sections covering specific STI policy areas discuss how these orientations might be translated into concrete policy actions.
- **Finally, for stakeholders working to promote the global STI community,** policy actions identified in the section on international co-ordination in STI will likely be of greatest use. This section aligns with and reframes actions raised in several other areas, such as funding and finance, market and structural conditions, and cross-government coherence, from the viewpoint of international collaboration and co-operation. Many of the actions also include specific focus on official development assistance and the representation of emerging economies in international STI activities.

Executive summary

Multiple crises are triggering turbulence, instability and insecurity in contemporary societies, with impacts on economies, the environment, politics, and global affairs. The climate emergency and growing socio-economic disparity require nothing short of a profound transformation of established operating models. Rising geopolitical tensions, rapid technological change, and the reach of crises like the COVID-19 pandemic have brought resilience and security to the fore as policy concerns. Tensions like these create pressures for the transformation of economies and societies, and more specifically, for their adjustment to future configurations that embody desirable traits, such as sustainability, resilience and inclusiveness.

To meet global challenges, governments will need to be more ambitious and act with greater urgency in their science, technology and innovation (STI) policies. Transformations depend on scientific knowledge and the development and deployment of enabling technologies. These, in turn, depend on well-functioning STI systems to generate and utilise relevant knowledge, technologies, and innovation at pace and at scale. Sustained investments and greater directionality in research and innovation activities are needed, and these should coincide with a reappraisal of STI systems and STI policies to ensure they are "fit-for-purpose" to contribute to transformative change agendas. In some instances, this may call for phasing out established practices, while in others, their evolution or maintenance will be key. Many of the reforms are well-known within the STI policy community yet pose significant implementation challenges.

The OECD Committee for Scientific and Technological Policy (CSTP) has developed the Transformative Agenda, with three core elements: transformative goals for STI to pursue, policy orientations for guiding STI towards transformative change, and STI policy areas where change may be most urgently needed.

The Transformative Agenda provides practical guidance for policymakers and other relevant stakeholders to formulate and implement STI reforms that will accelerate positive economic and societal transformations. Six transformative policy orientations have been identified. These consider the value of STI policy being more: (i) directed toward addressing economic and societal challenges, (ii) driven by broad-based values, (iii) attentive to scaling up and diffusing multiple forms of innovation, (iv) active in promoting phase-out of harmful technologies, (v) systemic and co-ordinated across multiple levels, and (vi) experimental and agile.

It also sets out policy actions for the practical scale-up and institutionalisation of reforms in ten different STI policy areas. All of the main aspects of STI policy and governance are covered, including research and innovation funding, human resources for science and technology, STI system co-ordination mechanisms, and evaluation and measurement.

While the Transformative Agenda provides a key starting point, more detailed guidance on the design and reform of STI policies will be supplemented by two additional forms of support:

- Modular policy guidance for each of the ten STI policy areas covered will discuss proposed key policy actions, potential implementation pathways and challenges posed by the status quo.
- Toolkits will provide step-by-step, interactive guidance to support users in translating policy challenges into feasible and context-specific actions.

Future CSTP projects may use peer learning methods to experiment with the formulation, design and implementation of STI policies targeting transformative change. A new series of OECD innovation policy country reviews on transformative STI policies could also be inaugurated.

1 The Agenda for Transformative STI Policies

What is the Agenda for Transformative STI Policies?

The world is facing multiple interconnected crises, from climate change and biodiversity loss to rising conflicts and geopolitical tensions. A majority of OECD countries are experiencing growing levels of inequality (Solarin et al., 2022[1]), while the COVID-19 pandemic has reversed progress on resolving between-country income inequality by several decades (UN, 2023[2]).[1] The pandemic has also emphasised the importance of resilience to deal with future shocks, while rapid technological change and growing strategic competition between the major powers have brought security to the fore as a key policy concern.[2] The climate emergency requires nothing short of a profound transformation of sectors like energy, heavy industry, agrifood and transportation, to shift towards more sustainable, inclusive and resilient operating models (OECD, 2023[3]) (IEA, 2021[4]).

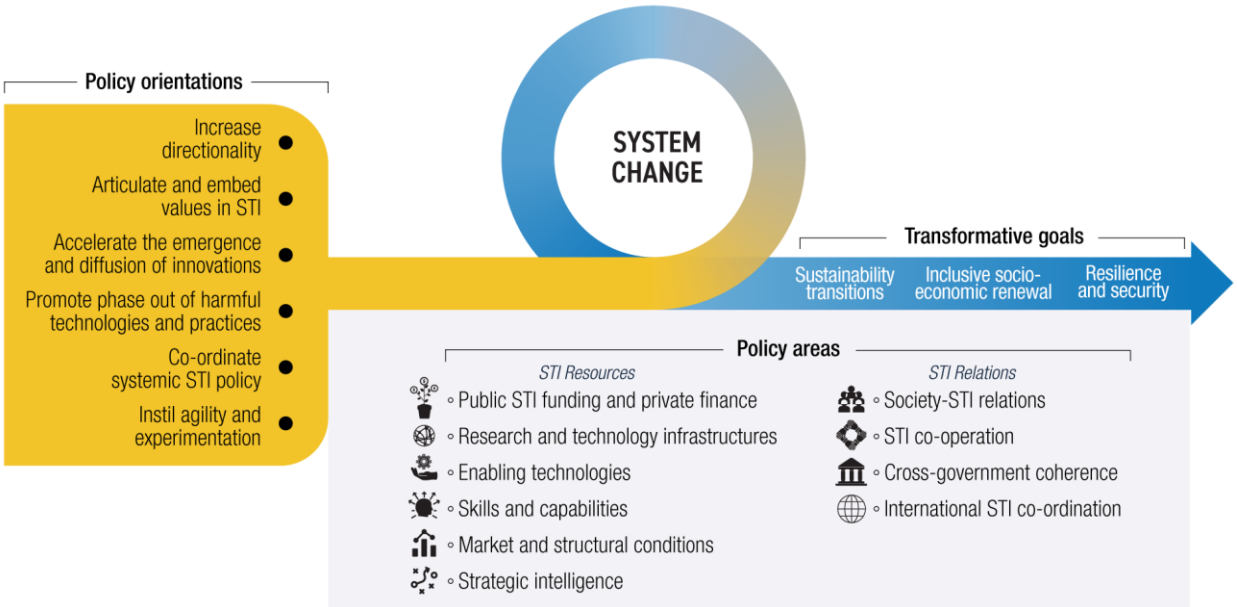
Science, technology and innovation (STI) are uniquely positioned to help drive the transformation of economies and societies to meet these challenges. However, depending on the national context, STI may need to reform to fulfil this potential. Among other things, achieving transformative change requires STI policies to be more directional and move beyond their traditional main focus on national competitiveness and economic growth (Diercks, Larsen and Steward, 2019[5]). Additionally, STI policies should be considered as part of a broader policy mix that includes policies from other sector-specific (e.g., health, agriculture, energy) and cross-cutting (e.g., education and trade) policy domains. Making these adjustments has implications for the governance, co-ordination and orientation of STI policies (Fagerberg, 2018[6]).

Against this background, governments may need to revisit STI policy frameworks, visions, targets and instruments with a view to adapting them or displacing them in favour of others that are fit-for-purpose to promote positive transformative change (Schwaag Serger and Palmberg, 2022[7]). To support this reappraisal and reform of STI policy, the Committee for Scientific and Technological Policy (CSTP) has developed the *Agenda for Transformative Science, Technology and Innovation Policies* (hereafter, the Transformative Agenda), which is comprised of three main components (Figure 1.1):

- **Transformative goals for STI to pursue**. The report articulates three goals: (i) Advancing sustainability transitions that mitigate and adapt to a legacy of unsustainable development; (ii) Promoting inclusive socio-economic renewal that emphasises representation, diversity and equity; and (iii) Fostering resilience and security against potential risks and uncertainties.
- **Policy orientations to help steer STI policy towards transformative change**. The report will discuss six policy orientations, which consider the value of STI policy being more: (i) directed toward addressing economic and societal challenges, (ii) driven by broad-based shared values, (iii) attentive to scaling up and diffusing multiple forms of innovation, (iv) active in promoting phase-out, (v) systemic and co-ordinated across multiple levels, and (vi) experimental and agile.

- **STI policy areas where change may be most urgently needed**. The report will consider ten STI policy areas that, taken together, constitutea broad STI policy mix. The Transformative Agenda outlines 4-5 key policy actions in each STI policy area that can help promote transformative change. The ten areas are as follows:
  - **STI resources:** STI funding and finance; research and technology infrastructures; enabling technologies; skills and capabilities; market and structural conditions; and strategic intelligence.
  - **STI relations:** between STI and society; between the public, private and non-profit sectors; across different parts of government; and at the international level.

Figure 1.1. The Transformative Agenda's transformative goals, policy orientations and STI policy areas



Note: The figure provides a visualisation of the different pieces of the Transformative Agenda and their interactions.

The remainder of the Transformative Agenda provides a high-level introduction to these three components. Sections focused on reforming specific STI policy areas will be supplemented by two additional forms of guidance in the future. These include the following:

- **Modular guidance** on the ten policy areas will provide more detail on proposed STI policy actions, potential implementation pathways and challenges posed by the status quo. These modules will also feature tangible, country-specific case studies to showcase emerging lessons and good practice and, ultimately, establish a common evidence base for policymaking.
- **Toolkits** will provide step-by-step, interactive online tools for users to translate STI policy challenges into feasible and context-specific actions. This additional guidance is currently under preparation and is briefly described in the final section of the Transformative Agenda.

Why a new Transformative Agenda for STI policies now?

STI policy and the transformative goals

The climate crisis, growing biodiversity loss, rising inequality and heightened geopolitical tensions create pressure on policymakers, researchers, industry and the public to reconfigure economies and societies in ways that improve mitigation, resilience and/or adaptation in the face of these challenges. Along these lines, the Transformative Agenda is built around achieving **three transformative goals**:

- **Advancing sustainability transitions** that mitigate and adapt to a legacy of unsustainable development from climate change, pollution and biodiversity loss, sometimes referred to as the 'triple planetary crisis'.[3] Socio-economic systems should evolve to satisfy the current needs of different individuals without compromising the ability of future generations to do the same (OECD, 2023[3]). Advancing sustainability calls for accelerated transitions in specific industries (e.g., fossil fuels to renewable energy), technologies (e.g., internal combustion to zero emission vehicles), and established models of production and consumption (e.g., from linear to circular economy).
- **Promoting inclusive socio-economic renewal** that emphasises accessibility, representation, diversity and equity. Income inequality has a sizeable and statistically significant impact on growth and is a key strategic consideration for economic development and societal outcomes (OECD, 2023[3]). In the context of sustainable development, 'just' green transitions should bring social, environmental and economic co-benefits (Altenburg and Assmann, 2017[8]) (OECD, 2023[9]) but will also need to address unequal starting points and the disproportionate impacts that can occur as a result (OECD, 2018[10]).
- **Fostering resilience and security** against risks and uncertainties posed by the growing emergence of systemic threats. Abrupt shocks, such as the COVID-19 pandemic, have demonstrated the importance of resilience to enable modern global socio-economic systems (e.g., supply chains, energy production systems) to anticipate, absorb, recover from and adapt to disruptive change (OECD, 2020, p. 11[11]) (Linkov and Palma-Oliveira, 2017[12]). These concerns are accompanied by rising strategic competition between countries in critical technologies and resources that underpin economic competitiveness and national security. Governments increasingly seek greater strategic autonomy to reduce vulnerabilities to supply chain disruptions and to enhance their national industrial base, particularly in advanced technologies (OECD, 2023[13]).

Concerns are mounting that progress made on achieving these goals to date is not proportionate to the urgency or magnitude of evolving global challenges. Transformations go beyond incremental change and call for ambitious measures in firms, governments and society more broadly.[4] These include mainstreaming mental models and frameworks that embrace transformations; new skills and capabilities to enact transformations; new relationships, for example, between the public and private sectors, between different sectors of the economy, and between advanced and less-developed economies to exchange and pool resources; and greater experimentation and learning that support multiple pathways to transformation and acknowledge its uncertainty and complexity.

While there are strong synergies and interdependencies between the transformative goals, insular efforts to advance specific goals may compromise others. For example, Open Science and international collaboration are key to effectively addressing collective global challenges but should also take account of national security risks (Molen et al., 2023[14]) (Federation of American Scientists, 2024[15]). The growing demand for renewable energy technologies should consider the increased need for metals and minerals, whose extraction has been linked to environmental damage, child labour, human rights abuses, and armed conflicts (Church, Crawford and Schaller, 2019[16]). In addition, there are various costs, such as volatile energy prices, energy security concerns, and economic disruption in regions dependent on fossil fuels extraction, that warrant consideration in efforts to phase out fossil fuels and reduce greenhouse gas

emissions. In some situations, difficult choices will be necessary and will require policymakers to prioritise – ideally in collaboration with impacted stakeholders – economic, environmental, and security-based policy objectives.

Science, technology and innovation are uniquely positioned to help drive transformation

Transformations are facilitated by scientific knowledge and the development and deployment of enabling technologies. For instance, STI activities and outputs can support policymakers, researchers, industry and civil society by:

- **Contributing to the advancement and expansion of knowledge that can be mobilised rapidly and applied in unforeseen ways**. Fundamental science provides an important foundation for applied research and the development of future technological and social innovations that support transformation. It is also often the case that significant breakthroughs emerge from the accumulation and combination of decades of curiosity-driven research across various fields. This was shown most recently in the rapid development of COVID-19 vaccines,[5] demonstrating how long-term investments in R&D contribute to societal resilience.
- **Accelerating the development and deployment of innovation and technology for transformative change**. Achieving the transformative goals requires attention to the development of novel STI-based solutions in some areas. For example, anticipated pathways to achieve net zero are based on the rapid development and deployment of a variety of pre-commercial technologies, such as electrolysers for green hydrogen production (IEA, 2023[17]).
- **Monitoring and anticipating the evolution of natural and social systems, including the negative impacts of specific technologies or practices**. Availability and timeliness of data and scientific research is necessary to take stock of and forecast the evolution of global challenges, like climate change, as well as the potential consequences of the rapid uptake or phase out of technology (e.g., threats to privacy and human rights) (OECD, 2023[13]). Research from the natural as well as the social and behavioural sciences also provides important insights into factors that lead to exclusion and the divergence of outcomes for different groups (e.g., the social determinants of health).
- **Building the skills and capabilities for industry, public research systems, government and society to respond effectively to system transformation**. Much STI activity is closely linked with tertiary education systems and contributes to technical and transferable skills that are important for transformative change across economies and societies. In addition, engagement between researchers and the public, through the communication of scientific knowledge, deliberate awareness building efforts, and public engagement initiatives, is key to improving literacy and public trust in STI.
- **Convening and co-ordinating STI system actors to co-operate on achieving the transformative goals**. Networks between industry, public research organisations and government, and the opportunities for knowledge exchange and capacity building they afford, are foundational to STI advances. Recent approaches have evolved to engage a broader spectrum of contributors, such as civil society and socially innovative actors, and improve the accessibility of scientific advancements through Open Science agendas. Such exchanges will be important to facilitate the development of appropriate and effective solutions to societal challenges, which are increasingly multidimensional, multi-scalar and interdependent.
- **Expanding and strengthening international linkages**. Transnational STI activities offer valuable opportunities for diplomacy and the reinforcement of shared norms and values through co-operation, collaboration and knowledge sharing. International STI linkages can be led by states but are also often built from the bottom-up, via individual researchers, research organisations and business firms.

There is also a need to reflect on the potential harms of STI

STI can also exacerbate problems associated with contemporary global challenges, including:

- **Climate change and environmental degradation**: Various technological advances and resulting production-consumption models can be linked to different dimensions of the 'triple planetary crisis'. For example, it is well established that human activities have been a main contributor to rising atmospheric concentrations of greenhouse gas emissions and corresponding changes in global climate patterns (IPCC, 2007[18]) (IPCC, 2022[19]) (Rosa et al., 2015[20]).
- **Inequality and societal challenges**: Technology-driven development often co-exists with, or may reinforce, absolute and relative poverty (Chataway, Hanlin and Kaplinsky, 2014[21]). Without appropriate distributive or inclusion measures, contemporary innovation pathways can exclude large segments of the global population as both producers and beneficiaries of change (Planes-Satorra and Paunov, 2017[22]).
- **Vulnerability to systemic threats**: The diffusion of disruptive technologies often catalyses shifts towards new ways of working and living, which can result in patterns of unemployment and require corresponding action (e.g., behavioural change, skills development, regulation, etc.) (Perez and Leach, 2022[23]). Novel technologies can also present entirely new risks, such as those introduced by digital technologies to democracy and social cohesion (e.g., cyber attacks and misinformation), while in other instances, technologies can exacerbate or augment established risks.

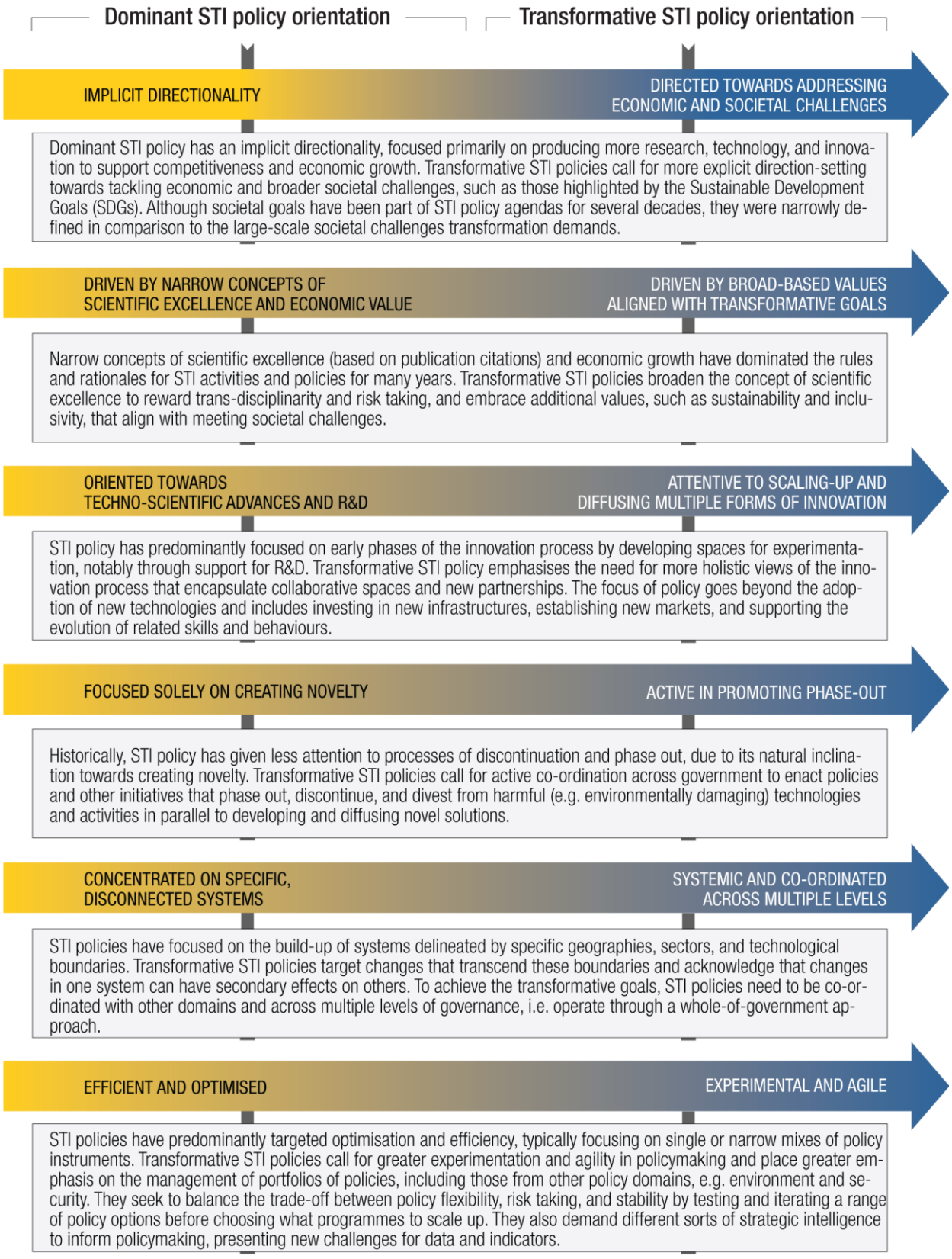
How does the Transformative Agenda differ from the status quo?

The transformative goals have featured in national and international research and innovation agendas for some time, but insufficient progress to date in achieving collective endeavours, such as the Sustainable Development Goals, suggests a simultaneous need for policymakers to more deliberately reform certain aspects of STI and STI policy systems (Ciarli et al., 2022[24]). Contributing to transformations and avoiding harms requires sustained investments and greater attention to directionality in research and innovation activities. While research excellence and national competitiveness remain essential considerations, STI activities should also embrace goals and practices that, by design, foster sustainability, inclusion, resilience and security. In some instances, this may require the phase out of established ways of doing things, while in others, the evolution or maintenance of current practices will be key. As with the greater focus being placed on engaging with the public and co-ordinating with other policy domains, STI policy reforms may entail a broadening of mandates to better reflect overlooked and new roles that research and innovation could play to address global challenges. Additional concrete examples are provided in the Transformative Agenda.

Achieving transformative goals often coincides with achieving reforms to address long-standing challenges in STI systems. For example, progress on a range of issues – such as strengthening various linkages in STI systems (e.g. between business and academia, between different parts of government, and between science and society), enhancing the skills and organisational capabilities of firms, and reducing precarity in research careers – will contribute to STI system reforms that hasten progress on the transformative goals. Likewise, directing STI systems towards goals like inequality and resilience can facilitate progress on these long-standing issues if transformation-friendly values are embedded in STI policymaking. Thus, the pursuit of the transformative goals provides an opportunity to promote structural reforms that address long-standing issues in STI systems and vice versa (Few et al., 2017[25]).

While they are hardly novel and have been in evidence for some time, broadly adopting the transformative goals would represent a shift in the orientation of STI policy. Figure 1.2 provides an overview of this potential shift, drawing a stylised distinction between a 'dominant' STI policy orientation (since the 1990s) and a more 'transformative' STI policy orientation that is now emerging.

Figure 1.2. A stylised comparison of 'dominant' and 'transformative' STI policy orientations



While this reorientation could see considerable continuation of existing STI policy goals and practices, it would also see important changes, building on and scaling-up experimentation with more directed, inclusive and systemic policy approaches. In this way, a more transformative STI policy orientation is likely to coexist with the dominant orientation, at least in the near term, with reforms occurring in a more incremental and evolutionary process, though abrupt changes are also possible in the face of future shocks and discontinuities (Diercks, Larsen and Steward, 2019[5]). Going forwards, and with a view to accelerating the move towards more transformative STI policy goals and practices, there are likely multiple pathways for reorientation, reflecting local conditions. Despite this variety, all pathways should be guided by a common set of 'STI policy orientations' to help drive transformative change.

2 Transformative STI policy orientations

Introduction

Implementing transformative change calls for more directional, co-ordinated and agile STI policies. While many countries have been experimenting with policy reforms for some time, these efforts would now benefit from being scaled up and institutionalised. . The Transformative Agenda identifies six policy orientations that should help point STI policies towards positive transformative change. These consider the value of STI policy being more: (i) directed toward addressing economic and societal challenges, (ii) driven by broad-based values, (iii) attentive to scaling up and diffusing multiple forms of innovation, (iv) active in promoting phase-out of harmful technologies and practices, (v) systemic and co-ordinated across multiple levels, and (vi) experimental and agile. These six policy orientations, which are cross-cutting and apply to all areas of STI policy, are summarised in Figure 2.1.

Figure 2.1. The Transformative Agenda's six policy orientations

Direct STI policy to accelerate transformative change

The scale and urgency of transformative change call for greater directionality in STI. But STI systems must also maintain research and technology diversity to contend with future uncertainties and develop absorptive capacities to access knowledge and technologies created elsewhere. Governments should cultivate organisational and governance capabilities to set directions along these lines and change course as needed.

Embrace values in STI policies that align with achieving the transformative goals

Values underpin how STI systems operate, including what activities are prioritised, how they are carried out and whom they benefit. STI policy should embrace broader values in pursuit of the transformative goals, placing greater emphasis on respecting human rights; promoting democratic values, safety and security, and sustainable development; and encouraging equity and inclusion.

Accelerate both the emergence and diffusion of innovations for transformative change

A mix of emerging and established science, technology and innovation is needed to achieve the transformative goals. STI policymakers should strengthen linkages between activities across innovation chains to help bridge the multiple 'valleys of death' facing the development, demonstration and deployment of novel technologies, and thereby accelerate the innovation cycle for transformative change.

Promote the phase out of technologies and related practices that contribute to global problems

Achieving the transformative goals requires deliberate policy action to phase out, discontinue, and divest from harmful technologies and practices. Ideally, these efforts should align with policies to promote the development and diffusion of novel solutions. They require co-ordination between STI policy and other policy areas with the requisite regulatory and fiscal power to promote phase out.

Implement systemic and co-ordinated STI policy responses to global challenges

Transformative change is non-linear, so STI policy should identify 'leverage points' for interventions that acknowledge positive and negative feedback dynamics and the necessity to sequence change to unlock potential pathways. Transformative STI policies should co-ordinate with other policy domains and across levels of government to steward systemic change and tailor interventions to specific sectors and places.

Instil greater agility and experimentation in STI policy

STI policymakers should take a deliberate and systematic approach to testing new ideas and promoting a culture that encourages risk tolerance and evaluation. They should utilise agile policymaking processes to prepare for and respond swiftly to emerging circumstances, targeting action to where it is most needed, while discontinuing ineffective activities. This requires a diverse range of strategic intelligence capabilities and resources.

Transformative STI policies are not specific to a narrow set of policy instruments but cover the full range of policy actions. The OECD Secretariat has mapped different types of policy instruments against the key policy orientations, as shown in Table 2.1. Governance instruments – including national strategies and agendas, the creation and reform of public bodies, including those that promote cross-government co-ordination and stakeholders' engagement, and strategic intelligence – are especially important. STI policymakers may need to cultivate novel governance and institutional capacities for transformative change that differ substantially from those that are in place at present. Other instruments, such as those providing direct funding to STI activities and promoting collaboration, as well as regulation and guidance, will also play significant roles and may benefit from reform. Policy instrument options are briefly discussed for each of the policy orientations below and in subsequent sections on policy actions.

Table 2.1. Leveraging different types of policy instruments in implementing the policy orientations

Types of policy instrument	Directional	Values	Whole chain	Phase out[6]	Co-ordinated	Agile
Governance	●●●	●●●	●●●	●●●	●●●	●●●
Direct financial measure	●●●	●●	●●●	●	●●	●●
Indirect financial measures			●●			●●
Collaboration and infrastructure	●●	●	●●●		●●●	●●
Guidance, regulation, and incentives	●●●	●	●●●	●●	●●	●

Note: Table 2.1 shows the relevance of different types of policy instruments to the implementation of the Transformative Agenda's six policy orientations. **Governance instruments**: Strategies, agendas and plans; Creation or reform of governance structure or public body; Policy intelligence; Formal consultation of stakeholders or experts; Horizontal STI co-ordination bodies; Regulatory oversight and ethical advice bodies; Standards and certification for technology development and adoption; Public awareness campaigns and other outreach activities. **Direct financial support instruments**: Institutional funding for public research; Project grants for public research; Grants for business R&D and innovation; Centres of excellence grants; Procurement programmes for R&D and innovation; Fellowships and postgraduate loans and scholarships; Loans and credits for innovation in firms; Equity financing; Innovation vouchers. **Indirect financial support instruments**: Tax or social contributions relief for firms investing in R&D and innovation; Tax relief for individuals supporting R&D and innovation; Debt guarantees and risk sharing schemes. **Collaboration and infrastructures instruments**: Networking and collaborative platforms; Dedicated support to research and technology infrastructures; Information services and access to datasets. Guidance, r**egulation, and incentive instruments**: Technology extension and business advisory services; Science and technology regulation and soft law; Labour mobility regulation and incentives; Intellectual property regulation and incentives; Science and innovation challenges, prizes and awards.
Source: Based on OECD Secretariat assessments. The policy instrument typology is from the EC-OECD STIP Compass policy instrument typology, 2023 edition (https://stip.oecd.org/assets/downloads/STIPCompassTaxonomies.pdf).

Direct STI policy to accelerate transformative change

The urgency and ambition of the transformative goals call for speedy collective action that prioritise both science and technology breakthroughs and the deployment and diffusion of existing technologies and knowledge. There is need for greater directionality in STI systems to meet the transformative goals, which will entail the mobilisation of STI actors and resources towards specified targets, typically an area of science or technology, or an economic goal or societal challenge. Such targets can be specified and implemented at different levels of aggregation, ranging from national strategies to the plans of individual organisations, such as firms and universities.

Efforts to cultivate organisational and governance capabilities will support governments in setting directions and changing course as needed. While policymakers influence STI directions most visibly through their own public investments in research and innovation, they can also help to articulate shared visions that mobilise firms (who account for most R&D and innovation activities in OECD countries) and public sector scientists (many of whom work within academic autonomy frameworks). Many governments are experimenting with novel policy instruments, such as challenge-based funding and mission-oriented innovation policies (MOIPs) that bring together multiple actors, including from different policy domains, as

well as firms and public-sector research organisations, to co-create and collaborate across innovation chains on transformative pathways (OECD, 2023[13]; Larrue, 2021[26]). Cross-government co-ordination with other policy domains is especially important, since market and structural conditions, such as regulations and standards, should be aligned to facilitate technology diffusion and phase out.

Policymakers should ensure their STI policy portfolios are appropriately balanced to target global challenges. The aim of transformative STI policy is not just to generate innovations as effectively and efficiently as possible, but also to direct them towards meeting chosen goals. Directionality is implicit in all policymaking by default, but the STI policy mix in many countries over the last few decades has become more 'horizontal' and 'agnostic' on the research and innovation areas it supports. There are benefits to adapting STI policy portfolios to more readily embody directionality towards the transformative goals, for example, through making greater use of instruments such as R&D grants and innovative public procurement (Uyarra et al., 2020[27]). At the same time, it is important that STI policy portfolios are able to contend with the uncertainty of unfolding events and developments, not to mention the uncertainties raised by advances in science and technological innovation themselves. Support to STI should therefore be sufficiently diverse to research, develop and deploy the necessary range of knowledge and a portfolio of technologies to tackle global challenges.

Embrace values in STI policies that align with achieving the transformative goals

The transformative goals mean STI policy should embrace a broader set of values. Values are an inherent element of all policy decisions. They are reflected in the STI priorities that governments set and enact through the activities and areas they support. They also underpin much of the logic that drives how STI systems operate. The transformative goals broaden the foundational values underpinning STI policy, placing greater emphasis on respecting human rights; promoting safety, security and privacy, democratic values, and sustainable development; and encouraging equity and inclusion.[7]

There are also values specific to science and technology, which emphasise principles such as trust, openness, transparency, reciprocity and responsibility in science and technology (Table 2.2). These provide a moral and political basis for the priorities and trade-offs that are a feature of all science and technology governance decisions.

Table 2.2. Specific values pertinent to science and technology governance

Specific values pertinent to science	Specific values pertinent to technology governance
• **Freedom of scientific research** encompasses the right to freely define research questions, choose and develop theories, and gather empirical material to question accepted wisdom and bring forward new ideas. • **Open science** refers to efforts to make the primary outputs of publicly funded research publicly accessible as a means for accelerating research. • **Research integrity** refers to certain values, norms, and principles that constitute good scientific practice, including trust, honesty, accountability, respect and responsibility. • **Reciprocity** involves the practice of exchanging research materials, outputs, and knowledge in a manner that benefits all collaborating partners.Equity is an important consideration with regard to reciprocity. • **Well-being of citizens** involves science responding to the needs of society.	• **Trustworthiness** includes ensuring that technologies, actors and their decisions can be counted on for accuracy, reliability and regulatory compliance. • **Responsibility** involves the attribution of the consequences, positive or negative, of actions and decisions related to technologies, as well as accountability to those affected or to society in general. • **Transparency** involves giving an open and honest description of information conveyed, its justification, and limitations, in language that is understandable and accessible. • **Technology stewardship** places a duty with sufficient expertise and knowledge to create and use technology in ways that are aligned with foundational values and promote public goods. • **Innovation for public good** emphasises the important benefits to society from technology innovation, and the need to lower unnecessary barriers to achieve that goal. • **Responsiveness** requires meeting the expectation that promised technological outcomes are delivered in a timely way.

Source: Adapted from OECD (2022[28]) and OECD (2024[29]).

In science, for example, a values-based approach can help design policies that promote open science while acknowledging the importance of working with trusted and values-aligned partners to advance responsible and diverse, equitable and inclusive international co-operation to address global challenges (OECD, 2022[28]). This may require actors to make choices when there is conflict between different policy objectives, such as economic, environmental, and security-based priorities. A values-based approach can also ensure that the development and governance of technologies are underpinned by high-level ethical standards and responsible practices (OECD, 2023[13]). Embedding values in the innovation process requires several steps, however, including building robust processes and forums in which to deliberate on the choice of values and how they should be applied across innovation chains (from R&D agenda setting through to technology diffusion and deployment) (OECD, 2024[29]). These require dedicated governance arrangements, including institutions for deliberation and decision-making, as well as strategic intelligence. Broader values can also be incorporated into policy instrument design, for example, in the selection criteria for grant funded projects.

Accelerate both the emergence and diffusion of innovations for transformative change

A mix of knowledge, innovation, and novel and existing technologies is needed to achieve the transformative goals. For example, the IEA estimates that more than a third of the emissions reductions required in 2050 to achieve net zero scenarios will come from technologies that are still in the lab (IEA, 2023[17]). Achieving net zero therefore requires a mix of new R&D and demonstration activities, together with the deployment and diffusion of existing technologies. Moreover, the resulting sustainability and digital transitions go beyond the adoption of new technologies and include investment in new infrastructures, establishment of new markets, development of new social preferences, and support for people of working age and communities in attaining new skills and opportunities as part of 'just green transitions' (Geels et al., 2017[30]). Non-technological innovations, including social and process innovations, among others,[8] will also make important contributions.

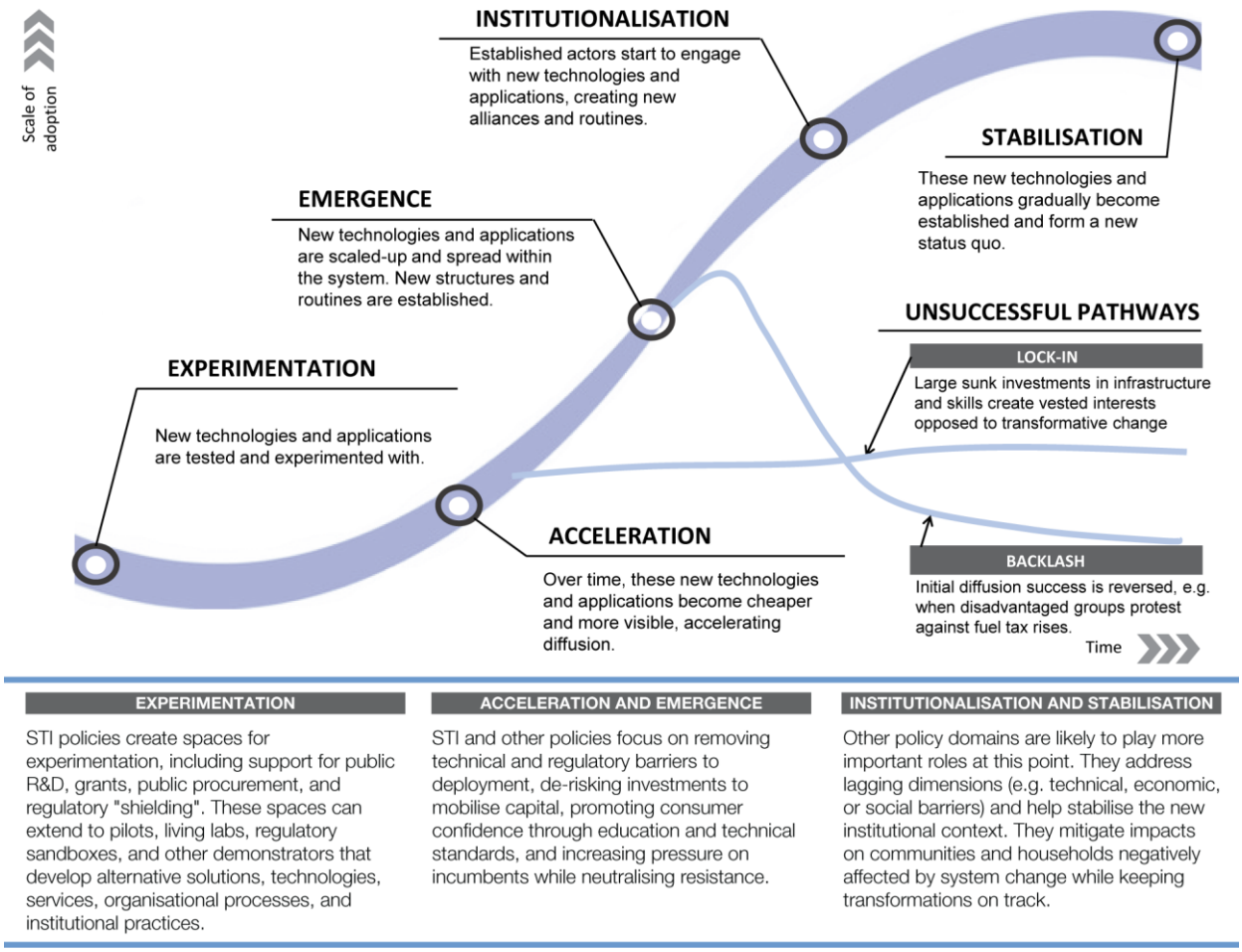
Transformations proceed in phases that typically follow S-shaped curve dynamics (Victor, Geels and Sharpe, 2019[31]; Meadowcroft et al., 2021[32]).[9] Due to their complexity, transformations rarely follow a linear process. Instead, they are made up of collections of diverse and iterative pathways where the pace of change ramps up and tapers off depending on the phase (Loorbach, Frantzeskaki and Avelino, 2017[33]). Summarising the phases as shown in Figure 2.2:

- A transformation may start with a relatively long period of **experimentation**, in which new technologies and practices are developed and tested and there is competition among promising but far-from-perfect alternatives. The aim of policy at this stage is to support a variety of alternative solutions to challenge and transform incumbent technologies and practices. In addition to bottom-up experimentation, policymakers can leverage major structural and institutional changes and reforms, such as new regulation or changes in international trade and investment patterns, to drive and support the emergence and diffusion of innovations for transformative change.
- Experimentation is followed by expansionist **acceleration and emergence** phases, which see growing convergence on standardised solutions and wide scale adoption. For this to happen, however, new technologies and practices need to cross 'valleys of death' between R&D activities and market entry. The aim of policy is to strengthen market formation by creating new customer demand and promoting price-performance improvements (Kivimaa and Kern, 2016[34]). As Figure 3 shows, many promising technologies and practices do not proceed beyond this phase because of lock-in and path dependency dynamics associated with established technologies and infrastructures. There can also be backlash, for example, where disadvantaged groups

successfully lobby against the abolition of environmentally damaging fuel subsidies and thereby weaken market incentives to pursue low-carbon innovation.

- In later **institutionalisation and stabilisation** phases, new arrangements become dominant, adjustments with adjacent systems are completed, and the regulatory framework is adapted to the new configuration. STI policies have a lesser influence during this phase.

Figure 2.2. Typical S-shaped curve of technology or practice adoption and system transformation



Source: Hebinck et al. (2022[35]) adapted from Loorbach, Frantzeskaki and Avelino (2017[33]); and Meadowcroft et al. (2021[32]).

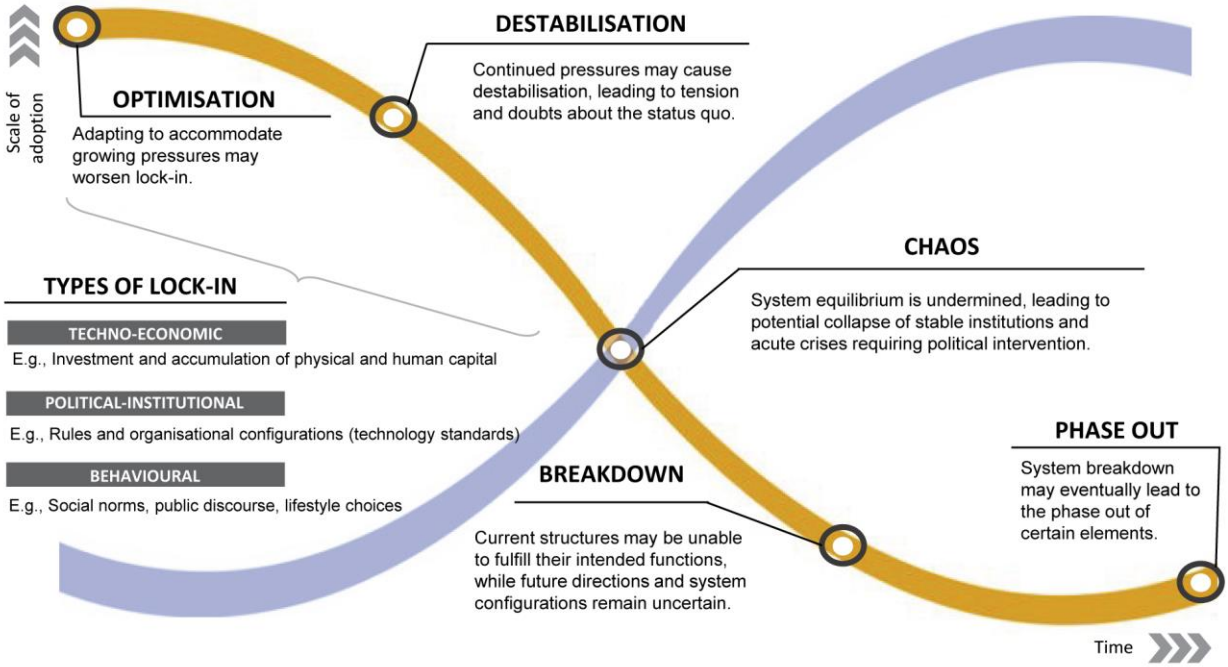
Promote the phase out of technologies and related practices that contribute to global problems

Achieving the transformative goals will require governments to deliberately enact policies to phase out, discontinue, and divest from harmful technologies and activities in parallel to policies that promote the development and diffusion of novel solutions (Rogge and Johnstone, 2017[36]). This aligns with policymakers more deliberately embracing values, such as sustainable development, safety and security, equity and inclusion, and innovation for the public good, in the design of policy. Without these interventions, there is substantial risk that emerging alternatives may be unable to compete with established solutions.[10] Phase out measures can help create or augment 'protected spaces', which might

be necessary to shield and scale up directional technologies, innovations, and practices. In addition, efforts to divest from certain sectors or activities should also be accompanied by measures that will protect impacted workers and communities.

The build-up of new technologies and practices co-evolves with the phase-out of established ones. Figure 2.3 shows an archetypal pattern of how phase-out can proceed. Established technologies and practices may come under continued, destabilising external pressure. This can lead to uncertainty and ambiguity and eventually to their phase out.[11] In successful transformations, these breakdown dynamics are accompanied by the build-up dynamics shown in Figure 2.2. Figure 2.3 is commonly referred to as the 'X-curve framework' and captures the co-evolution of patterns of build-up and breakdown (Loorbach, Frantzeskaki and Avelino, 2017[33]) (Hebinck et al., 2022[35]).

Figure 2.3. Complementary patterns of technology diffusion and phase out



Source: Hebinck et al. (2022[35]) adapted from Loorbach, Frantzeskaki and Avelino (2017[33]). Types of lock-in adapted from Rosembloom and Rinscheid (2020[37]).

Historically, STI policy has paid less attention to processes of discontinuation and phase out due to its natural inclination towards creating novelty (Koretsky et al., 2023[38]). Other policy areas with regulatory and fiscal powers have taken the lead, for example, through policies designed to motivate or require specific actions from industry (e.g., technology bans and carbon taxes), and through diminished support for established technologies and practices (e.g., elimination or reduction of fossil fuel subsidies) (Kivimaa and Kern, 2016[34]). STI policies should co-ordinate more closely with these related policy areas to articulate transformative policy portfolios. Other efforts that can facilitate phase out include programmes to support the adaptation or discontinuation of particular practices and processes, disincentivising experimentation with existing damaging technologies,[12] and repositioning research and technology infrastructures to prioritise the needs of transformative innovations over established alternatives.

Implement systemic and co-ordinated STI policy responses to global challenges

Accelerating transformative change means intervening in complex systems. Most change in systems proceeds incrementally, involving piecemeal adjustment of technologies and societal practices. Although transformations can be sudden and swift, they typically take time to unfold and move through different phases that face various impediments. The urgency to address global challenges means that deliberate action may be necessary to accelerate respective transformations. This involves multiple adjustments to technologies, business practices, regulatory frameworks, and consumer behaviour. Transformative change is non-linear, however, which makes it messy and unsuited to 'command-and-control' notions of policy intervention. Predicting development paths is impractical since the direction and outcomes of innovations are unknown, and shifts in economic or political conditions, societal opposition, or unexpected events can stall, reverse, or reorient transformative pathways (Meadowcroft and Rosenbloom, 2023[39]). So while transformations call for bold and urgent policy interventions, these should be sufficiently flexible to seize new opportunities and tackle unexpected challenges as they arise.

STI policy should identify 'leverage points' for interventions that acknowledge positive and negative feedback dynamics, the distribution of power within systems, and the necessity to sequence change to unlock potential pathways. These leverage points represent places within systems in which one small change can lead to bigger changes everywhere (Meadows, 1999[40]). In this respect, there is growing interest in using public policies to help trigger 'positive tipping points' (Tàbara et al., 2021[41]; Systemiq, University of Exeter and Bezos Earth Foundation, 2023[42]; UN, 2023[43]) that reinforce feedbacks and virtuous cycles to accelerate transformative change.[13] A more deliberate search for positive tipping points could identify opportunities to accelerate transformative change (Lenton et al., 2023[44]; Sharpe and Lenton, 2021[45]). However, this will require policymakers and governments to embrace and cultivate a different set of skills, capabilities and processes, in complement to what may currently be in place.

Progress on global challenges requires collective and orchestrated action. Targeting global challenges and their broad agendas explicitly involves a wide mix of stakeholders from firms, government, public research and civil society, which increases the complexity for co-ordinated action. Governments can cultivate organisational capabilities to support collective efforts that set directions and steward systemic change itself (OECD, 2018[46]). For example, policymakers can work with stakeholders to develop and implement shared goals and visions for transformation, which can help reduce uncertainty and ambiguity, as multiple actors work towards common goals and solutions. This can occur domestically as well as internationally with the use of tools like global climate agreements. Policymakers should also deploy other policy instruments, including funding for collaborative R&D, mission-oriented innovation policies (MOIPs), and networking and collaborative platforms, to promote collective action on transformations.

STI policy interventions should also be tailored to specific sectors and places, since transformation journeys tend to be at different phases and face different impediments. For example, sectors like energy (IEA, 2023[17]), agrifood (OECD, 2022[47]), and transport (ITF, 2023[48]) are at different phases in their decarbonisation journeys, face different barriers and enablers, and will depend on different reconfigurations of actors and technologies to reach net zero (OECD, 2023[49]). While low-carbon innovations are rapidly diffusing in transport, a focus on emissions reduction as part of sustainable productivity growth is only more recently emerging in agrifood (OECD, 2023[50]; Victor, Geels and Sharpe, 2019[31]). Given this variety, STI policymakers should co-ordinate with other policy domains to design and implement transformative systems policies (Table 2.3). In some of these areas, frameworks and good practice may already exist to enable transformations.[14] At the same time, transformations should be promoted at multiple levels of government (local, regional, national and supra-national), which calls for their active co-operation to clarify roles and responsibilities and to ensure that policies at all levels of government are well aligned. For example, in federalist jurisdictions, many of the policy domains outlined in Table 2.3 are, at minimum, the partial responsibility of sub-national authorities. More generally, a strong

place-based approach is beneficial to tailor STI policy interventions to specific local conditions (OECD, 2019[51]; OECD, 2020[52]).

Table 2.3. Examples of horizontal and sectoral public policy areas closely related to STI policy

Examples of horizontal policies	
Tax and finance	**Public spending**, including departmental spending and capital investment, which determine the level of public expenditure on STI; **Taxation**, including general corporate taxes, carbon taxes, R&D tax incentives, etc., that influence the propensity of firms to conduct R&D and innovate; **Financial services regulation**, which circumscribe the risk profiles and investment roles institutional investors and others can assume.
Economy, industry and trade	**Market rules and regulations that promote competition** and consumer protection, which impact rates of innovation in economies; **New industrial policies**, including subsidies, that seek to promote high-tech sectors of the economy; **Investment promotion**, both inward and outward, that shape the profile of business ecosystems and business activities in an economy and their international linkages, which, in turn, influence the types and levels of R&D and innovation performed; **International rules on investment**, such as state aid regulations, which place restrictions on the types of support governments can offer innovative firms; **Trade policies**, including export promotion, international agreements that remove trade barriers, and export controls and other measures to promote economic security and resilient supply chains, all of which shape the locations of production and consumption of high-tech products and services; **Subsidisation or support for the development of infrastructure** or deployment of STI-based solutions with applications across sectors, such as fibre broadband or cleantech.
Education and employment	**Investments in education**, from early learning to tertiary education, including adult learning and retraining, which provide the skills necessary for R&D and innovation; **Promotion of access to education and training**, particularly for under-represented groups, that promote equity and diversity in the STI workforce; **Regulations and promotion of international workers**, which influence the pool of scientists and other knowledge workers in an economy.
Environmental protection	**Environmental regulations** that promote biodiversity, pollution control, waste management, natural resource management, etc., which shape R&D and innovation in the public and private sectors, both to develop new products and services and to ensure regulatory compliance.
Foreign affairs and international development	**Science and technology diplomacy initiatives** that promote international STI linkages, particularly with low- and middle-income countries; **Official development assistance**, which increasingly incorporates STI elements, including voluntary technology transfer on mutually agreed terms, and the development of STI skills and capabilities, to bolster global efforts that tackle global challenges.
Examples of sectoral policies	
Health and social care	Sectoral policies in many OECD countries include considerable **R&D and innovation support activities and capabilities**, which can complement funding initiatives under the direct purview of STI ministries and agencies. Sectoral policies include significant **standards and regulation** that shape related STI activities. These are especially important in later phases of transformation, since they shape the environment for new technologies to emerge and diffuse and for established ones to be phased-out. Sectoral policies play leading roles in creating markets for new technologies and innovation, for example, through **public procurement**.
Energy	
Transport	
Agriculture and food	
Construction	
Defence	

Instil greater agility and experimentation in STI policy

Governments should further embrace policy experimentation to develop the novel solutions needed to achieve the transformative goals. There is increasing recognition that conventional regulatory approaches are ill-equipped to contend with the complexity, unpredictability, and speed of innovation and broader system transformations (Centre for Regulatory Innovation, 2021[53]).[15] Emerging tools and methodologies that embody experimentation, engagement, and iteration represent promising advancements in this respect. Policy experimentation involves a deliberate and systematic approach to testing new ideas, policies, or interventions to assess their potential impact and inform evidence-based decision making. It can enable STI policymakers to balance policy flexibility and stability by testing and

iterating a range of policy options before choosing the programmes to scale up (Kuhlmann and Rip, 2014[54]).

Experimentation requires particular skills and tools, but also a culture that encourages evaluation, risk tolerance, critical assessment of the status quo and a willingness to investigate, negotiate and integrate diverse insights (Lindner et al., 2016[55]). Many governments are already exploring ways to create 'safe spaces' for experimentation inside the public sector, using, for example, policy innovation labs (Monteiro and Kumpf, 2023[56]), living labs (Fuglsang and Hansen, 2022[57]), trusted environments (OECD, 2020[58]), regulatory sandboxes (Attrey, Lesher and Lomax, 2020[59]), and crowdsourcing platforms (Arnold et al., 2023[60]). However, their adoption remains relatively nascent in most jurisdictions and sectors. These efforts can now be scaled up to become more routine. In this respect, top-level sponsorship and sustained support will be key, together with the adoption of robust methodologies for experimentation and corresponding measurement and evaluation (OECD, 2023[61]) (Monteiro and Kumpf, 2023[56]).

Pursuing transformative goals involves novelty, uncertainty and complexity, thus it is important that policies can be swiftly adapted to reflect new developments. Transformations can follow multiple pathways and tend to evolve differently than originally expected on account of complex dynamics. Continuous reassessment and adaptation of priorities and programming is necessary to leverage opportunities, avoid bottlenecks and deadlocks, and act on evolving evidence and public sentiment in real time. This calls for agile policy-making processes that prepare for and respond quickly and effectively to changing circumstances, emerging trends, and evolving challenges, targeting action at where it is most needed. Agility also refers to the ability to halt policy initiatives that are unsustainable or do not deliver expected outcomes. Among the practices governments are already using are horizon scanning, early-warning systems, and nowcasting (Arnold et al., 2023[60]).

A diverse range of strategic intelligence is essential for agile and experimental STI policy to succeed. This includes benchmarks, real-time monitoring, and future-oriented analysis to anticipate change and the threats and opportunities it entails, to monitor system performance, and to monitor policy interventions, including their effectiveness and efficiency (Robinson, Winickoff and Kreiling, 2023[62]; Rotolo et al., 2017[63]). Inclusive and anticipatory intelligence tools, like technology assessment and foresight, can help identify future opportunities and threats, and help formulate collective long-term visions and near-term action plans. Formative evaluations can support learning on the non-linear cause and effect relationships that characterize transformations and the aggregate impact of policy portfolios across different industries and societal systems (Janssen, 2019[64]).

3 Translating the policy orientations into policy actions

Introduction

In translating the policy orientations into concrete actions, policy measures should be directed at specific actions that may be needed to help achieve transformations rather than 'business-as-usual' outcomes. Depending on the policy area, such actions might, for example, integrate directionality and targeted values into policymaking processes; support, as required, the development, demonstration, deployment and phase out of a diversity of STI activities and outputs; and develop portfolios of policies that are co-ordinated, agile and experimental. Transformations may require the phase out of established ways of doing things, while in other instances, the evolution or maintenance of current practices may be key. Many of the necessary reforms are familiar to the STI policy community, but barriers remain, for example, in bridging aspirational strategy with the development and implementation of concrete policy interventions and in scaling-up and institutionalising corresponding policy innovations.

Transformative change is often associated with radical reforms, but small incremental changes may cause a system to shift qualitatively where it is close to a tipping point (Feola, 2015[65]). In most instances, however, transformation is likely to be a long-term process triggered by a number of different events that together contribute to a wider shift (Few et al., 2017[25]). Some of these events may be disruptive shocks and discontinuities that policymakers can leverage to enact major structural and institutional reforms to drive transformative change. At the same time, a progressive series of incremental changes in a policy mix can also combine into a deeper intervention that disrupts the status quo and creates system-wide change (Schumer et al., 2022[66]) (Allen and Malekpour, 2023[67]). This perspective lies at the heart of the Transformative Agenda, and acknowledges that bringing about a fundamental transformational change in STI will require changes across many fronts (HM Treasury, 2022[68]), adapting as lessons are learnt on what does and does not work (Jetel, 2022[69]). All aspects of STI policy and governance are implicated (Figure 3.1) and can be considered in terms of:

- **STI Resources:**: STI funding and finance, research and technology infrastructures, enabling technologies, skills and capabilities, market and structural conditions, and strategic intelligence.
- **STI Relations**: between STI and society; between the public, private and non-profit sectors; across different parts of government; and at the international level.

This section introduces some of the main challenges in these STI policy areas and outlines a suite of corresponding policy actions that could facilitate the transformation of STI and STI policy systems. These are summarised in Table 3.1 and Table 3.2. Some policy actions will be easier to implement than others, depending on local conditions in a country or sector. The OECD is preparing additional policy guidance to aid policymakers to implement these policy actions and the Transformative Agenda's policy orientations more broadly.

Figure 3.1. The ten STI policy areas addressed in the Transformative Agenda

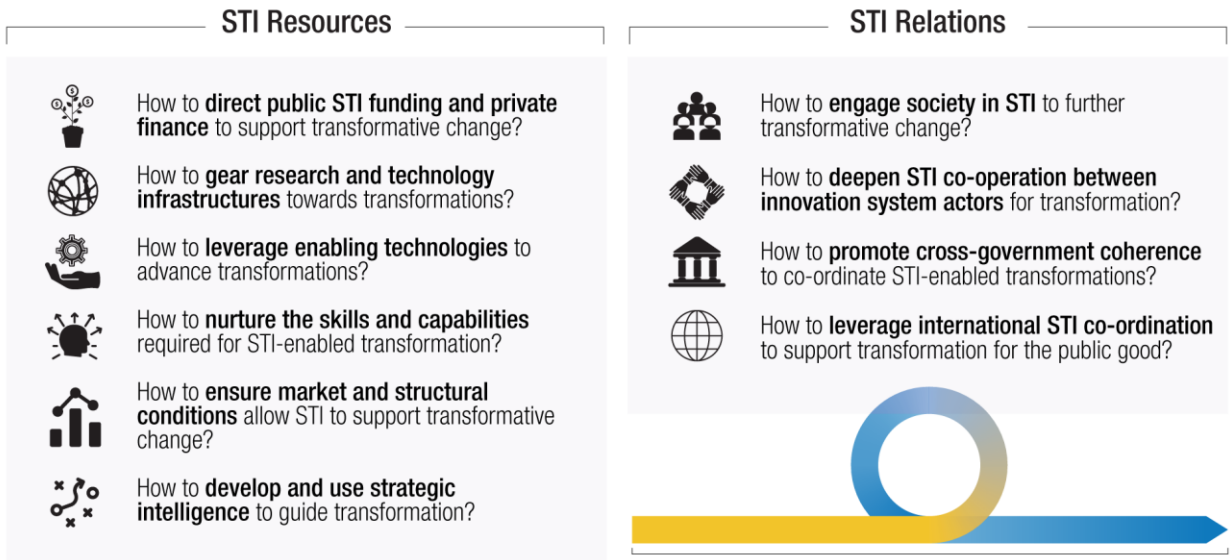


Table 3.1. STI 'resources' policy areas and associated key policy actions for transformation

Policy area	Key policy actions
1. Public funding and private financing of STI activities	• Introduce governance arrangements that promote agile STI funding and financing • Broaden stakeholder engagement and decision criteria in STI funding instrument design and implementation • Deploy funding portfolios that include significant support for high-risk high-reward research and the development of breakthrough technology • Socialise some higher levels of risk to encourage multiple investors to co-finance transformative STI
2. Research and technology infrastructures	• Adopt strategic funding approaches that enhance stability, while enabling agility and synergies within a portfolio of activities • Support the co-ordinated and collaborative development and use of RIs/TIs to tackle complex and interconnected global challenges • Confirm RIs/TIs as sites for generating and stewarding high-quality data and technology for transformations • Leverage RIs/TIs to address skills scarcity and mismatch associated with transformation
3. Enabling technologies	• Accelerate the productivity of research through AI and automation in science • Mainstream the digital transformation into achieving the transformative goals • Leverage digital technologies to facilitate decision-making in STI policy and administration • Embed shared values into technology development and governance to advance public good while mitigating against potential risks • Reinforce international co-operation in STI development through common ethical practices, norms and understanding of good technology governance
4. Skills and capabilities	• Monitor and respond to misaligned skills supply and demand to facilitate equitable transformative change • Invest in building digital expertise and specialised skills and knowledge in diverse communities • Cultivate a scientific research workforce that is resilient and diverse • Build organisational capabilities to manage the cross-cutting and long-term nature of transformation
5. Structural and market conditions	• Co-ordinate with other policy areas to level the playing field for transformative technology and innovation to successfully compete • Promote international technical standards to unlock new markets and weaken the appeal of established technologies • Adopt regulatory approaches that are agile, technology neutral and human-centered • Use IPR systems to drive innovation and foster the wide uptake of transformative technologies • Harmonise, legitimise and institutionalise transformative investment approaches
6. Strategic intelligence	• Support novel and distributed sources of strategic intelligence to tackle global challenges • Develop arrangements to combine different sorts of strategic intelligence for STI policymaking • Cultivate skills and capabilities that promote the utilisation of strategic intelligence in STI policymaking • Implement a strategic 'policies for evidence' agenda that promotes the production and use of strategic intelligence for transformative change

Table 3.2. STI 'relations' policy areas and associated key policy actions for transformation

Policy area	Key policy actions
7. Society-STI relations	• Improve STI communication practices to cultivate mutual trust and understanding • Engage diverse and inclusive perspectives to develop more robust and relevant STI-based solutions • Mainstream and scale up public participation in STI activities and policymaking • Advance and empower citizen-led STI activities through experimentation and knowledge sharing
8. STI co-operation	• Build innovation ecosystems and value chains that support transformation • Develop flexible governance approaches for collaborations targeting transformation • Promote collaborative platforms to support innovation for transformative change • Disrupt established knowledge hierarchies that impede the adoption of insights from diverse disciplines
9. Cross-government coherence	• Actively co-ordinate and align priorities and interventions across government • Promote consistency of policy actions across levels of government • Harmonise government infrastructure and procedure to improve knowledge sharing and co-operation • Streamline complex governance arrangements
10. International co-ordination in STI	• Align national transformative STI priorities and co-ordinate funding for research and innovation activities to address global challenges • Strengthen Open Science and knowledge sharing to improve global resilience and scale up efforts to address collective challenges • Safeguard research integrity and security of the global research system • Scale up inclusive multilateral partnerships to respond effectively and equitably to global challenges • Foster international market conditions that enhance competitiveness and equitable access to emerging STI-based solutions

01 Public STI funding and private finance

How to direct public STI funding and private finance to support transformative change?

Transformative change calls for ambitious levels of STI investment over a long period, covering all parts of the innovation chain, from exploratory fundamental research to the deployment and diffusion of tested technologies. These investments are distributed among a variety of different actors within public research and innovation systems as well as private industry. As such, they include public funding for STI from research and innovation ministries and agencies, as well as from sectoral ministries and agencies in areas like energy, transport, agriculture and health. They also cover private financing for STI, for example, by research and innovation performing firms (including foreign direct investors),[16] banks, non-profit or philanthropic organisations, and other sources of innovative finance, all of which can be spurred by public policies.

As well as sustaining R&D expenditures, governments should consider the ways their investments are made and which parts of the innovation chain they target. For instance, in supporting research performed in universities and public research institutes, governments need to consider balancing challenge-based R&D funding, which can help direct research and innovation efforts towards the transformative goals, with curiosity-driven basic science, which is associated with various breakthroughs and contributes to a global stock of knowledge that furnishes societies with resilience.

The last two decades have seen considerable change in the policy instruments deployed by most OECD countries to support business R&D, with a near-universal shift from direct funding support, e.g., through grants, to a greater reliance on R&D tax incentives. While both types of measure are useful, the growing urgency to deal with key societal challenges, like climate change, points to value in taking a more directive approach.

A further important policy question is how much to invest on diffusion of existing technologies and innovation on the one hand compared to R&D and technology demonstration on the other. While both are needed, the relative importance of deployment support (market pull) vis-à-vis R&D and demonstration support (technology push) should increase with the movement from immature technologies towards technologies closer to market competitiveness (OECD, 2023[3]) (Cervantes et al., 2023[70]).

STI policymakers can pursue the transformative goals through the following policy actions:

- **Introduce governance arrangements that promote agile STI funding and financing**: More flexible funding and agenda setting processes can improve the resilience of STI systems and their ability to respond more readily and effectively to emerging crises and evolving societal challenges. While funding flexibility (e.g., reallocation or carry-over of funds) has increased in a majority of OECD countries in recent years, it will be important for this to be accompanied with greater focus on particular objectives and accountability (OECD, 2017[71]). This may require fundamental changes to agenda and budget setting processes,[17] and amendments to the underlying evaluation and incentive frameworks used in public R&D to disrupt STI system siloes. There is also scope to continue to experiment with policy innovations adopted in response to the COVID-19 pandemic, such as improved communication between funders and recipients and rapid review processes (OECD, 2023[72]). Promoting flexibility could also encompass a range of funding mechanisms targeting STI in firms, such as sustainable finance labs and agile innovation funds targeting companies new to R&D (Loorbach, Schoenmaker and Schramade, 2020[73]; Enterprise Ireland, 2022[74]). In addition, challenge-based or mission-oriented research should leave sufficient

autonomy for researchers to choose among diverse technology avenues to achieve set objectives, in order to allow for the development of "unexpected" technology solutions (de Silva et al., 2023[75]).

- **Broaden stakeholder engagement and decision criteria in STI funding instrument design and implementation**: The barriers to achieving the transformative goals are multidimensional, multi-scalar, interdependent, and evolving. Challenge-based research benefits from to integrate expertise and insights from different disciplines and different sectors of society. Expanding the public funding allocated to broadly collaborative activities will be key, yet in many countries and scientific fields, collaborative research, particularly those that are trans-disciplinary, remain relatively rare. Academic research and assessment processes that prioritise traditional academic outcomes, such as journal publications, can disincentivise collaborative STI activities that seek to convene actors from different scientific disciplines and sectors. Policymakers should revisit and, as far as it is feasible, reorient established ex ante assessment and ex post evaluation funding criteria frameworks to incentivise inter- and trans-disciplinary research.[18]
- **Deploy portfolios of funding instruments that include significant support for high-risk high-reward research and the development of breakthrough technology**: An increasing concern of the scientific community in recent years is that research funding processes have become too conservative and encourage only incremental advances in STI. Failure to encourage and support research on risky, 'out of the box' ideas may jeopardise a country's longer-term ability to compete economically and to harness science for solving national and global challenges. Policymakers should provide political long-term support for risk-taking and long-time horizons for high-risk high-reward research,[19] while funding agencies should experiment with different approaches (OECD, 2021[76]).[20] Similarly, direct measures, including R&D grants, loans and credits, and public procurement, are superior to indirect measures (e.g. R&D tax incentives) for supporting breakthrough innovation and technology in firms that will be critical to advancing sustainability transitions and the resilience of socio-economic systems (OECD, 2021[77]). Measures like these should be more prominent in STI policy portfolios.[21] Given scientific research and technological innovation are inherently uncertain, policy support should 'spread bets' on a diversity of solutions using a portfolio approach. This will help avoid technological lock-ins and develop the absorptive capacities to access knowledge and technologies developed elsewhere. A portfolio approach should also balance funding support across stages of the innovation chain and promote interactions and complementarities between stages to help steward ideas from conception to application and bridge particular 'valleys of death'.[22] There is no one-size-fits-all and composition of these portfolios and the research areas, technologies, industries, and other forms of innovation that are prioritised will depend significantly on the current context of individual countries and their desired future visions.
- **Socialise some higher levels of risk to encourage multiple investors to co-finance transformative STI**: Several capital market failures discourage the allocation of private investment into technologies that promote transformative change.[23] For example, there are often longstanding alternatives to low carbon technologies, while deep technology solutions are well-known for being more intensive with timelines for development that do not align with private sector investment requirements. Governments can use risk-mitigation tools, such as first-loss mechanisms and equity guarantee schemes, to help firms cross 'valleys of death' at various stages in the innovation chain. Approaches like 'blended finance', which initially emerged as an innovative tool in the development community to crowd in private financing for sustainability projects in developing countries (Samans, 2016[78]), are gaining traction in the STI policy field as a way to combine public and private finance across the innovation chain (OECD, 2022[79]) (Miedzinski et al., 2020[80]). Governments should continue to experiment with these approaches, which have the potential to direct STI finance and help scale up private investments in R&D and innovation to better meet global challenges in both developed and developing countries.

02 Research and technology infrastructures

How to gear research and technology infrastructures towards transformation?

Research infrastructures (RIs) and technology infrastructures (TIs) are essential for state-of-the-art research and innovation in most scientific and technological fields. RIs are diverse in nature, from very large and/or international RIs to smaller facilities hosted in many public research institutes, research and technology organisations (RTOs) and universities, including technical and polytechnic universities. An increasing number of RIs are composed of several facilities located in different sites. RIs also include e-infrastructures and digital repositories, as well as high-performance computing infrastructures. TIs are similar to RIs in that they have a service mission and are located in RTOs and universities. However, their activities aim to produce technological and social innovations for the needs of industry and the public sector rather than fundamental research. This distinction can be context and country-specific as many facilities support both basic and applied research.

RIs/TIs have the potential to contribute significantly to the advancement and acceleration of transformative change agendas. In part, this is rooted in the diversity of roles they play in STI systems. Besides knowledge production, RI/TIs convene diverse collaborations, generate and store high-quality data, develop and deploy enabling technologies, and deliver education and training. Notably, facilities found in RIs/TIs, such as demonstrators, testbeds, piloting facilities and living labs, are essential for supporting the challenging stage of solution demonstration and scale up. At the same time, there is also a risk that RIs/TIs represent consequential sites of lock-in, in terms of substantial sunk investments and obligations to influential stakeholders, which can hamper transformative agendas.

STI policymakers can pursue the transformative goals through the following policy actions:

- **Adopt strategic funding approaches that enhance stability, while enabling agility and synergies within a portfolio of activities**: RIs/TIs represent long-term strategic investments in R&D, which are indispensable for enabling and developing research and innovation with broader socio-economic impacts. They therefore require careful planning and continuous and stable support, which goes beyond mere financial considerations (OECD, 2017[81]). Furthermore, their sustainability cannot be solely addressed at the individual facility level. The diversity of missions and users of RIs/TIs requires that funders and governments take a broader and more collaborative portfolio management approach to allow for long-term planning, to reconcile the need for flexibility with financial constraints, and to facilitate the development of synergies (OECD/Science Europe, 2020[82]).
- **Support the co-ordinated and collaborative development and use of RIs/TIs to tackle complex and interconnected global challenges**: RIs/TIs are uniquely positioned as 'system intermediaries' to support interdisciplinary and intersectoral research and innovation efforts that tackle cross-cutting issues, reduce duplication and uncover synergies. Many RIs are open to scaling up activities with industry but are limited by current expectations and incentives. Structural siloes and procedural bottlenecks challenge the development of integrated RIs/TIs ecosystems and diverse collaborations (Larrue and Strauka, 2022[83]). Yet the COVID-19 crisis highlighted the added value of RIs/TIs working together to address complex scientific and social issues (OECD, 2023[84]). Experimenting with more flexible and inclusive in-kind contribution and access models can promote integrated RIs/TIs ecosystems that strengthen the connection of fundamental science to solving complex societal challenges (OECD, 2023[85]). Incentivising co-investment and co-development with industry can strengthen partnerships and extend the influence of public funding for TIs.

- **Confirm RIs/TIs as sites for generating and stewarding high-quality data and technology for transformations**: The data management and stewardship capacities and policies of RIs/TIs will play an important role in advancing Open Science agendas, while also contributing to the security and integrity of research activities and outputs. Co-ordination and co-operation across RIs will be key to improving data findability and interoperability across scientific fields through transparent standards (GloPID-R, 2019[86]). Furthermore, due to requirements for high excellence and the validation of data by a broad user base, RIs/TIs represent a unique source of trustworthy data for policymakers and the public. The facilities and expertise of TIs to test, standardise and scale-up technologies, including deep technologies, will be crucial in developing new solutions. TIs are also a critical component of the quality infrastructure and underlying strategic intelligence used to ensure the quality and safety of STI-based solutions (Kellermann, 2019[87]) (Brown, Knee and Blind, 2022[88]). Funders should thus provide the necessary resources to support these activities. In addition, collaborative and innovative funding models, such as the acceptance of blended finance will be helpful in aligning facility services and activities with the partner and user needs.
- **Leverage RIs/TIs to address skills scarcity and mismatch associated with transformation**: RIs/TIs can contribute to developing general and specialised skillsets (e.g., digital expertise), as well as organisational capabilities (e.g., SME absorptive capacity) required for transformative change. They are well positioned to contribute to capacity building efforts through increased labour mobility, industry partnerships, and multi-modal training. Furthermore, as RIs/TIs are increasingly involved in complex societal challenges, they are now being used by broader non-expert communities, including the public, entrepreneurs and start-ups. Supporting their use by new communities can therefore help to improve the scientific and digital literacy of non-experts and the dynamic capabilities of firms. Leveraging RIs/TIs in this way requires the assessment and adaptation of access mechanisms, such as better integration of remote access mechanisms, to facilitate use by targeted, and potentially new communities. Corresponding and sustained funding commitments may also be warranted to improve the ability of RIs/TIs to support increased demands and new user needs.

03 Enabling technologies

How to leverage enabling technologies to advance transformations?

The emergence, scale-up and deployment of enabling technologies are transforming STI activities. Digital technologies, for example, are already accelerating innovations for sustainability transitions, with artificial intelligence (AI) and the Internet of Things (IoT) underpinning smart grids, decreasing energy and resource consumption in industry, and increasing the efficiency of wind and solar farms (Amoroso et al., 2021[89]) (OECD, 2022[90]). Likewise, harnessing biotechnologies, such as gene-editing and synthetic biology, promises a revolution in multiple industries as well as contributing to sustainability transitions (OECD, 2014[91]) (Philp and Winickoff, 2018[92]). Some of these enabling technologies are well-established, but many are in active development, characterised by rapid expansion, evolution, novelty and uncertainty in trajectory and impact (OECD, 2024[29]). Many are also converging with potential links between them and resultant synergies and benefits. Less consideration has been given to the role of enabling technologies in research for global challenges, but using AI, for example, could raise the productivity of science, allowing more scientific knowledge to be discovered, and helping science become more efficient (OECD, 2023[93]).

The ongoing dynamics of emerging and converging technologies are largely outside the scope of government intervention, but governments may diagnose what is going on and on that basis define interventions that can modulate developments and nudge them in better directions (OECD, 2014[94]). In particular, accelerating the development and scale-up of relevant technologies can be supported over the long-term through additional efforts to anticipate and mitigate the social disruptions that may follow. For example, digitalisation comes with risks related to cybersecurity and privacy and can be costly due to the need to build up specific infrastructures and specialised capacities (Winickoff et al., 2021[95]), while persistent digital divides hamper development for many and leave already marginalised populations further behind (OECD, 2021[96]). Good technology governance – defined as the process of exercising political, economic and administrative authority in the development, diffusion and operation of technology in societies (OECD, 2018[97]) (OECD, 2023[98]) – can help shape technological development to help ensure more beneficial and responsible innovation.

STI policymakers can pursue the transformative goals through the following policy actions:

- **Accelerate the productivity of research through AI and automation in science**. While AI is penetrating all domains and stages of science, its full potential is far from realised. In a context in which some scholars contend that science is becoming harder, AI in research could support the ability of OECD countries to grow, innovate and address global challenges – from climate change to new contagions – and help address the economic burden of rapid population ageing. Furthermore, laboratory robots could revolutionise some domains of science, lowering the cost and hugely increasing the pace of experimentation. Policy makers and actors across research systems can do much to accelerate and deepen the uptake of AI and automation in science. For example, they can target research where breakthroughs are needed to deepen AI's uses in science and engineering, promote progress through ambitious multidisciplinary programmes, increase access to high-performance computing and software for advances in AI and science, introduce steps to improve the reproducibility of AI research, and address the potential dangers entailed in the dual use of AI-powered discovery (OECD, 2023[93]).
- **Mainstream the digital transformation into achieving the transformative goals**: Many modern innovations are new products, processes or business models that are at least partly enabled by digital technologies or embodied in data and software. Innovation processes themselves are changing in an era of digital transformation, for example, with the use of AI-based analytics that

allow for large-scale experiments in research and new virtual simulation and prototyping techniques for developing new products. Creating new value with data-driven innovation requires firms to adopt newer and more advanced ICTs, to invest in intangible assets, and to develop or acquire relevant skills. The scope for supportive STI policy interventions is vast, and includes measures that raise firms' digital capabilities (particularly among SMEs), improve open access to data (with protections for privacy and security) and data infrastructures (such as high performance computing), and promote public-private R&D partnerships (OECD, 2019[99]; Gierten et al., 2021[100]; OECD, 2021[101]).

- **Leverage digital technologies to facilitate decision-making in STI policy and administration**: The rapid pace of technological change, coupled with a pressing need for solutions to address global challenges, mean policy makers are pressed to develop STI policies at speed, in situations of high uncertainty and, in some cases, around potentially controversial technology fields. The deployment of digital tools, such as AI, can extend and augment the capacity of policymakers and researchers to monitor, build on, and integrate real-time intelligence and/or scientific advancements into policymaking and STI activities, and help broaden the evidence base on which research is assessed. However, realising this potential involves overcoming several barriers related to data quality, interoperability, digital skills, sustainable funding and data protection regulations. Ministries and agencies responsible for STI policies and programmes should co-ordinate on digital policy systems and share resources as part of a coherent policy framework for data sharing and re-use across the public sector (OECD, 2020[102]).
- **Embed shared values into technology development and governance to advance public good while mitigating against potential risks**: Innovation actors should seek to align technological development with institutional and social values, e.g. through the development of guidelines, codes of practice and regulation in accordance with the stage of technology development (OECD, 2024[29]). Such alignment can both help maximise benefits of innovation as well as produce more support among stakeholders and in society. The *OECD Framework for the Anticipatory Governance of Emerging Technology* can help guide this approach to technology policy by encouraging the embedding of values throughout the innovation process, including at earlier phases (OECD, 2024[29]). Beyond this, concrete action to better reflect collectively held values and priorities in technology governance could be achieved through the participation of citizens in STI activities and policy development.
- **Reinforce international co-operation in STI development through common ethical practices, norms and understanding of good technology governance**. There is a mismatch between the transboundary nature of technology and the jurisdictional boundaries of governance and regulation. The development, use and effects of emerging technologies span national borders, highlighting the importance of multilateral approaches to governance. Deepening strategic competition (OECD, 2023[103]), while an engine of innovation, carries the danger of putting downward pressure on the controls that might be necessary to promote accountable and responsible innovation. This points to value of efforts to internationally co-create common ethical practices, norms and understanding of good technology governance. Principles and guidelines are an attractive modality for international, transnational and/or global actors to make moral and political commitments with some flexibility and accommodation for differences and changing circumstances (OECD, 2024[29]).

04 Skills and capabilities

How to nurture skills and capabilities required for STI-enabled transformation?

Transformative change calls for policy initiatives that address gaps in the skills and organisational capabilities of firms, governments, research actors, and the public.[24] Current deficiencies relate to both technological and "softer" skills, e.g., information-processing skills, socio-emotional skills and metacognitive skills (OECD, 2015[104]) (OECD, 2020[105]) (OECD, 2023[106]) (OECD, 2023[107]). Addressing these deficiencies will require a multi-agency approach that considers both supply- and demand-side perspectives. However, there is also a lack of empirical understanding on what skills and capabilities are required to achieve the transformative goals, as well as the skills likely to be required in the new socio-economic systems that will emerge.

Many skills and capabilities gaps relate to new ways of working and impact a diversity of stakeholders. For example, policy that is more directive, experimental, anticipatory, systemic, and inclusive will require policymakers to use skills and organisational processes that are often under-developed, such as integrating empirical evidence into decisions and operating with long-term perspectives (OECD, 2021[108]). With respect to national STI systems, the precarity of research careers and limited representation of certain demographics have implications for the ability of STI systems to generate knowledge, technologies, or innovations that are aligned with the needs of diverse groups (OECD, 2021[109]). More broadly, transformative change from sustainability and digital transitions, as well as other technological advancements, is expected to create mismatch between skills demand and supply that disproportionately impacts marginalised groups (Kanger, Sovacool and Noorkõiv, 2020[110]).

STI policymakers can pursue the transformative goals through the following policy actions:

- **Monitor and respond to misaligned skills supply and demand to facilitate equitable transformative change**: Sustainability and digital transitions are disrupting labour markets and will likely exacerbate existing inequalities (OECD, 2023[106]) (Global Deal, 2023[111]). Better anticipating skills needs, for example through industry and skills mapping or through skills foresight exercises, can help advance transformations (OECD, 2019[51]). Policy innovations may also address skills mismatch. For example, some jurisdictions have established micro-credential initiatives to allow organisations and individuals to rapidly acquire precise sets of modularised and accredited skills (Varadarajan, Koh and Daniel, 2023[112]).[25]
- **Invest in building digital expertise and specialised skills and knowledge in diverse communities**: Enabling technologies, such as digital tools, will radically transform STI and sociotechnical systems. For example, digital tools are critical to ensuring that data is accessible and reusable and have the potential to augment human capacity. Policy should support a range of stakeholders in cultivating and maintaining related skills. This may be in the form of novel training and education opportunities for the public and low-tech industries to help them adopt and adapt to new technologies. Policy should also target the digital competencies of SMEs, e.g., through publicly supported training (OECD, 2019[51]). There is a parallel opportunity to support the development of more specialised skills and knowledge for the research community to embed legal, ethical, and security considerations into digital or data-based activities (OECD, 2020[113]).
- **Cultivate a scientific research workforce that is resilient and diverse**: Lacking diversity and resilience of the research workforce has been driven largely by established evaluation and incentive frameworks, extreme competition for funding and declining tenured positions (OECD, 2021[109]). Current findings indicate that policymakers can help to address underlying issues, in part, by adapting evaluation frameworks. Ideally, evaluation would encompass a broader framing

of research excellence and performance that includes multiple research outputs, different modes of research and public and policy engagement. Additionally, taking steps to improve the diversity of career pathways available to doctoral and postdoctoral researchers could aid in the retention of a resilient research workforce that is also representative of society (OECD, 2023[114]). For example, policy could be used to facilitate international and inter-sectoral mobility, or the development of transferrable skills (e.g., project management, teamwork and communication).

- **Build organisational capabilities to manage the cross-cutting and long-term nature of transformation**: Governments, the public research system, and industry will need specific organisational capabilities to respond effectively to complex, interconnected and rapidly evolving societal challenges (OECD, 2021[108]). New processes and ways of working that promote reflexivity, learning and adaptation are needed to handle complexity, uncertainty and ambiguity (Borrás et al., 2023[115]). Dynamic capabilities are important to the ability of firms to contribute to and take part in transformative change, and thus, the effective advancement of such change. For example, recent findings suggest that organisational agility (i.e., capability to identify and pursue opportunities and adapt to change) is fundamental to the ability of firms to develop circular business models and related products and production systems (Castro-Lopez, Iglesias and Santos-Vijande, 2023[116]). Within government, translating experimentation to impact will require policy skills and organisational capabilities to adopt a more systematic approach at the level of strategy development as well as policy implementation.[26]

05 Market and structural conditions

How to ensure market and structural conditions allow STI to support transformative change?

The roles science and technological innovation can play in tackling the transformative goals are shaped by a wide range of structural and institutional factors. These can be far ranging, including legal instruments that influence the structure and operation of commercial, financial, labour, and intellectual property markets; the formation and substance of regulation and standards; corporate taxation; trade and investment policy; the availability of underlying physical infrastructure; and less formal institutions, such as ethics, culture and norms, among others. Factors such as industrial structure, natural resource endowment, macroeconomic conditions, geography and geopolitics are also important in shaping which STI activities occur and what outcomes are deployed.[27]

These framework conditions, which typically arise outside the immediate remit of STI policy, are potentially important leverage points for promoting STI-enabled transformative change. They may also raise significant barriers to change. For example, despite global intentions to reduce public subsidisation of fossil fuels, government support for fossil fuels almost doubled in 2022 to reach more than USD 1.4 trillion, as governments introduced substantial initiatives to mitigate the impacts of high energy costs on households and firms (OECD, 2023[117]). Such subsidies slow the phase out of fossil fuels and the adoption of low-carbon technology alternatives.

STI policymakers can pursue the transformative goals through the following policy actions:

- **Co-ordinate with other policy areas to level the playing field for transformative technology and innovation to successfully compete**: Considering decarbonisation as an example, STI policies can help reinforce the impacts of carbon prices by supporting innovations that lower the cost of green technologies, making them competitive with existing technologies.[28] In this way, STI policies can partially substitute for low carbon prices, which supports the case for even stronger STI policies (OECD, 2023[3]) (Cervantes et al., 2023[70]). Another example of the importance of co-ordinating with related policy areas lies in infrastructures, such as energy storage, smart grids, and charging stations for electric vehicles, which are essential for sustainability transitions. These are the responsibility of multiple government agencies, some at the sub-national level, which demonstrates the importance of cross-government coherence on decarbonisation efforts.
- **Promote international technical standards to unlock new markets and weaken the appeal of established technologies**: International technical standards are essential for the diffusion and interoperability of emerging technologies and the creation of markets for technology products and services. In the race to net zero, for example, standards can effectively complement emission pricing and incentive-based policies to create demand for low-carbon innovations, induce the phase-out of obsolete technologies, and ultimately drive decarbonisation. An example is the standardisation of plugs for electric cars across vehicles and charging stations. Such standards are best set at the international level and at least call for international co-ordination of national standards.
- **Adopt regulatory approaches that are agile, technology neutral and human-centered**: There is growing recognition that conventional regulatory approaches are ill-equipped to contend with the complexity, unpredictability, and speed of innovation and broader system transformations (OECD, 2021[118]) (Centre for Regulatory Innovation, 2021[53]). Promising tools and methodologies are emerging to improve experimentation, engagement, and iteration in this respect, though their adoption remains relatively nascent in most jurisdictions and sectors. The adaptation of current

"set and forget" regulatory approaches to frameworks intended to "adapt and learn" will impact the full regulatory cycle (OECD, 2021[118]) (OECD, 2021[119]). Policymakers and regulatory authorities may consider developing more adaptive, forward-looking and outcome-focused processes from regulatory assessment to enforcement. Such efforts can apply emerging governance approaches, featured, for example, in the OECD Framework for Anticipatory Governance of Emerging Technologies (OECD, 2024[29]). In turn, this will require efforts to broaden public and stakeholder engagement; strengthen domestic and international co-operation; and harness opportunities provided by soft law and protected spaces for experimentation.

- **Use IPR systems to drive innovation and foster the wide uptake of transformative technologies**: IPR systems should incentivise innovation and support diffusion of technologies on voluntary and mutually agreed terms to help meet global challenges such as climate change and access to affordable medicines. IP systems enable the sharing of technologies via market mechanisms such as voluntary licensing agreements, patent pools, and stakeholder-led voluntary commitments (Cervantes, Copeland and Zarnic, 2018[120]) (Garden, 2023[121]). Policymakers can promote these mechanisms, together with non-IP based approaches, such as open science partnerships (Gold, 2021[122]) and open source technologies, to improve knowledge and technology diffusion on voluntary and mutually agreed terms.
- **Harmonise, legitimise and institutionalise transformative investment approaches**: While sustainable finance approaches are increasingly popular, several challenges still undermine and hinder the efficient mobilisation of capital to support environmental, social and governance (ESG) objectives, including limited transparency and comparability of ESG methodologies and metrics. The international community has a role to play in convening collaborative and accelerated actions to address limited reliability, comparability, consistency, and transparency of metrics and to develop global baseline standards (Boffo and Patalano, 2020[123]) (OECD, 2022[124]). Through approaches such as 'science-based targets' (OECD, 2021[125]), STI can inform best practice for ESG metrics and improve the quality and consistency of data and strategic intelligence being used.

06 Strategic intelligence

How to develop and use strategic intelligence to guide transformation?

Strategic intelligence refers to the provision of data, knowledge and evidence and its utilisation in decision-making processes related to the formulation of STI policies and strategies, allocation of resources and governance of science and technologies (Robinson, Winickoff and Kreiling, 2023[62]; Rotolo et al., 2017[63]). It includes the findings of research commissioned by governments, scientific advice based on the latest available research evidence, policy and programme evaluation, monitoring and benchmarking using statistics and indicators, and future-oriented analysis, including forecasting and modelling, strategic foresight and technology assessment. As such, strategic intelligence can be sourced directly from scientists ('science for policy'), STI system and policy analysts, and a broad range of stakeholders engaged in deliberative or consultation policy processes.[29] Strategic intelligence tools are often used in combination and gather intelligence produced in multiple locations in a so called "distributed intelligence" system. The system is also distributed insofar as other STI stakeholders can often access and use much of this intelligence in their own decision-making processes.

Transformative STI policies demand knowledge and evidence to support direction-setting, experimentation and learning in contexts that are systemic, transdisciplinary, complex and uncertain. These demands may require new or significantly adapted knowledge institutions and infrastructures to be built, as well as new skills and organisational capabilities to be developed. Such developments likely amount to a transformation in the production and use of strategic intelligence itself.

STI policymakers can pursue the transformative goals through the following policy actions:

- **Support novel and distributed sources of strategic intelligence to tackle global challenges**: Transformations are wide-ranging and are characterised by non-linear dynamics in complex systems. Changes in the fundamental properties of a system and the way it behaves have important implications for analysis and the estimation or forecasting of future outcomes. Simple extrapolation from past experience will fail to foresee the way that a system may behave after it has been transformed or once the process of change has started (HM Treasury, 2022[68]). Yet many of the economic principles, models, and decision-making tools used by governments are designed for use within contexts of 'marginal' or incremental change, where technologies, markets and other economic structures are relatively stable. Different tools can be applied to support transformative change when the aims and context of policy include widespread innovation and structural change. These should consider uncertainties, opportunities, local knowledge and context – something that necessarily involves continued engagement with a broad range of stakeholders, including vulnerable and marginalised communities, in a distributed intelligence system (EEIST, 2022[126]).
- **Develop arrangements to combine different sorts of strategic intelligence for STI policymaking**: A specific challenge for governments is to make sense of the range of data available, and in particular to combine and synthesise knowledge and evidence from different sources that have different formats and have been produced for different purposes. Different knowledges have their own assumptions, own language and concepts, own infrastructures and own professional communities that can act as barriers to using diverse evidence in policymaking. To help tackle these issues, countries can develop cross-cutting intelligence infrastructure for STI policies (OECD, 2023[13]); address deficits in adequate infrastructure to enable the sharing of social science data (GloPID-R, 2019[86]); and promote the harmonisation and mutual understanding of definitions and processes used in data collection and management.

- **Cultivate skills and capabilities that promote the utilisation of strategic intelligence in STI policymaking**: Many countries note a persistent disconnect between the generation of strategic intelligence and its integration into policy decisions (Monteiro and Dal Borgo, 2023[127]). While this is a longstanding concern for the producers of strategic intelligence,[30] governments often lack the capacity and resources to incorporate strategic intelligence insights into STI policymaking. Governments can take various measures to support the translation of intelligence into policy decisions. For example, they can create dedicated strategic intelligence units, develop training courses for public servants and policymakers in strategic intelligence tools, and promote their direct involvement in strategic intelligence generating activities such as strategic foresight and participatory technology assessment. Embedding scientific expertise in policy making, for example, through policy fellowship schemes for scientists, can also be useful. Social scientists have useful insights, which government should leverage, on how countries might nurture political cultures that are favourable to using these kinds of activities to achieve transformative goals (Meadowcroft, 2011[128]).
- **Implement a strategic 'policies for evidence' agenda that promotes the production and use of strategic intelligence for transformative change**: The current knowledge and evidence base that supports policy decisions, such as indicators and statistics, can further evolve to meet the complexity and uncertainty of STI-enabled transformation. A more strategic approach to data and analysis of STI systems means raising awareness of the incentives and rules that make data fit-for-purpose to serve strategic and operational policy needs. The 'policies for evidence' agenda promoted by OECD in response to its Blue Sky Forum (OECD, 2018[129]) seeks to instil a shared sense of responsibility among decision makers over data, statistics and evidence on STI and concerted action among them to guide and sustain evidence-building and evidence-using efforts. Governments should aim to bring together scattered initiatives and exchange on best practices on priority-setting, governance, resource allocation and effective data stewardship. STI policy makers should recognise and realise to its full potential their responsibility for the generation, upkeep and integrity and accessibility of considerable amounts of administrative data relevant to the monitoring of STI systems and policies.

07 Society-STI relations

How to engage society in STI to further transformative change?

Society-STI engagement represents a spectrum of activities (i.e., communication, consultation, and participation) by which civil society engages with STI activities and outputs, as well as with STI policy. Everyday use of scientific results and technology is perhaps the most well-recognised point of engagement. At the same time, there is increasing recognition of the merits and necessity of more active public engagement in the development of STI activities and policy. Furthermore, STI activities alone cannot drive transformations. Inclusive and people-centered STI activities and policy will be a key component of achieving all three transformative goals. Public engagement is the most expedient and effective path to addressing the needs and concerns of different social groups, including under-represented perspectives, and broader socio-economic impacts (Paunov and Planes-Satorra, 2023[130]).

Widespread social acceptance is required to accelerate the adoption of STI-based solutions and to facilitate the development of legitimate transformation policies with strong public support. Recognising the importance of public agency and influence in the adoption of STI-based solutions will help to address technocentric framings that are often implicit to STI policy agendas and will allow for more systematic consideration of non-technological innovation, such as social or grassroots innovation.

STI policymakers can pursue the transformative goals through the following policy actions:

- **Improve STI communication practices to cultivate mutual trust and understanding:** Digital technologies afford new opportunities for societal engagement. They also pose significant challenges, such as the proliferation of mis- and disinformation that can lead to public distrust and polarisation, shown by the COVID-19 pandemic response to have adverse effects on the security and resilience of national socio-economic systems. As a result, there is recognition that it is important that STI communication practices evolve to maintain public trust and improve the ability of citizens to understand and contribute to STI activities and outputs. STI communication that is transparent, inclusive, ethical, accountable, objective, and timely should be recognised as good practice (OECD, 2023[131]). It may also be necessary to expand scientific codes of conduct to safeguard scientific integrity, include public communication responsibilities, and to more clearly delineate the roles and responsibilities of producers and users (e.g., policymakers) of science advice.[31]
- **Engage diverse and inclusive perspectives to develop more robust and relevant STI-based solutions:** Complex societal challenges often impact communities differently depending on the intersection of various demographic characteristics (e.g., social determinants of health). Additional efforts, such as investing in science literacy and/or digital connectivity, are important to address the exclusion of particular demographics. Empirical evidence also indicates that accessing insights from these groups often requires non-traditional approaches to mitigate or, at minimum, account for factors that contribute to under-representation (e.g., lack of willingness or desire to participate).[32] In this regard, social and behavioural scientists should be engaged in the creation of safe, inclusive and open spaces for dialogue.
- **Mainstream and scale up public participation in STI activities and policymaking:** Facilitating the proactive and systematic integration of public insights into STI activities and policymaking processes will require institutional change (e.g., policy and research evaluation), innovative processes, and sufficient resources (Bauer, Bogner and Fuchs, 2021[132]). The allocation of funding to societal engagement activities is often at odds with academic incentive frameworks and austerity trends in public spending (EEA, 2019[133]). While more funding for societal engagement would be

beneficial, STI policymakers and researchers can also look to leverage capacity and resources that may already exist within and beyond STI systems. For example, behavioural and social scientists, as well as communication professionals, can contribute substantial tacit knowledge to such efforts.[33] Top-down support from elected officials and high-level decision-makers is also an important enabler in establishing successful participatory processes (CSTP survey).

- **Advance and empower citizen-led STI activities through experimentation and knowledge sharing:** In addition to mainstreaming the use and evolution of mechanisms like citizen science, transdisciplinary research, and participatory technology governance, policymakers and researchers should empower bottom-up citizen-led activities. Engaging citizens at the start of scientific projects can strengthen alignment between research methods and expectations with societal needs and help to reframe which questions are being asked (Sauermann et al., 2020[134]). Tapping into the public discourse can also aid policymakers in accelerating the equitable diffusion and phase out innovation and technology. International knowledge sharing and communities of practice will be key to demonstrating the impact of social innovation and societal engagement and accelerating collective learning.

08 STI cooperation

How to deepen STI co-operation between innovation system actors for transformation?

STI co-operation supports the need to work systematically and across sectors to deliver the transformative goals. Co-operation involves a mix of innovation system actors, including firms of different sizes, public research actors, the government, and civil society, that co-ordinate efforts to mobilise resources, build capacity, share information, and formulate and implement policies supporting STI development. Common forms of co-operation include public-private partnerships, academia-industry collaborations, technology and knowledge transfer agreements, government-academia collaboration, research consortia, interdisciplinary collaboration, multi-stakeholder platforms, innovation clusters and ecosystems, among others.

Governments have a long tradition of promoting linkages in STI systems. For instance, they already deploy a policy mix of funding, regulation, information services, and specific governance arrangements to spur and deepen inter- and transdisciplinary and industry-academic relations. Policy measures have also supported various intermediary actors to work as brokers between two or more parties in the innovation process (Mignon and Kanda, 2018[135]; de Silva et al., 2023[75]). Promoting STI co-operation that bridges research, economic, and societal priorities will be key in addressing societal challenges. STI policy can support co-operation by encouraging new actors to engage in collaborative networks, widening the scope of collaborations, and challenging established networks hampering transformation (Grillitsch et al., 2019[136]). For example, engaging a variety of actors across industry, research institutions and civil society in co-creation initiatives was key to providing urgent responses to the COVID-19 pandemic (Kreiling and Paunov, 2021[137]).

STI policymakers can pursue the transformative goals through the following policy actions:

- **Build innovation ecosystems and value chains that support transformation**: The emergence of new value chains and innovation ecosystems that bring together cross-sectoral actors with complementary skills can be drivers of transformation (Pigford, Hickey and Klerkx, 2018[138]). However, new value chains can suffer from systemic challenges, notably a lack of funding for demonstration and ambiguous regulatory frameworks (OECD, 2019[139]; Winickoff et al., 2021[95]) (Philp and Winickoff, 2019[140]). These barriers can prevent collective public-private action and hinder market update of emerging solutions. Policy can create the framework conditions to overcome such barriers, for example, by promoting public support for testing and demonstration (e.g., by investing in new test infrastructures), using regulatory sandboxes, and supporting innovation-oriented public procurement (de Silva et al., 2023[75]) (OECD, 2023[61]).
- **Develop flexible governance approaches for collaborations targeting transformation**: Cross-sectoral social partnerships (e.g., for profit, non-profit, social enterprise, government/public) are increasingly used to address societal challenges (Ordonez-Ponce, Clarke and Colbert, 2021[141]). They bring opportunities to develop sustainable collaborative business models, usually defined at an organisational level, to the level of partnerships, and are aimed at integrating economic, ecological, and social value creation strategies. However, efforts to promote such models can be undermined by lack of access to funding and data access policies (Winickoff et al., 2021[95]). For instance, STI policy can address some of these gaps in data access, e.g., by promoting the use of standardised access procedures (Bustamante et al., 2023[142]; OECD, 2023[143]). Open Science partnerships, for example, can promote free public access to publications, data, and materials

(Gold, 2021[122]). Blended finance can also be leveraged to develop values and align incentives for all partners (Garden, 2023[121]).

- **Promote collaborative platforms to support innovation for transformative change**: New institutional arrangements, such as collaborative platforms, are emerging to co-ordinate a diverse set of actors across the public and private sectors. Collaborative platforms entail a technological architecture that allows their members to innovate rapidly, but also to collaborate with many external players who can use the platform for their own innovations (Winickoff et al., 2021[95]). For example, collaborative platforms can support the implementation of mission-oriented innovation policies by promoting the alignment and convergence of different actors. Additionally, they can assume an intermediary role by, for instance, acting as an impartial voice for new actor networks to promote transformation, or facilitating experimentation activities to change existing rules and regulations (Kanda et al., 2020[144]). Collaborative platforms can also harness the potential of digitalisation to convene actors to tackle the transformative goals. Digitalisation can support convergence and inclusivity in new collaborations by facilitating data sharing and management, opening up and diversifying innovation ecosystems, and decreasing costs and geographical barriers (OECD, 2020[102]).
- **Disrupt established knowledge hierarchies that impede the adoption of insights from diverse disciplines:** Collaborations involving stakeholders from multiple scientific disciplines can generate more complete scientific evidence and STI-based solutions for global challenges (OECD, 2023[84]). However, transdisciplinary activities bring additional complexity into scientific processes, on account of the traditional disciplinary organisation of academia and associated infrastructures, and the involvement of non-academic actors (OECD, 2020[105]). They also require a disruption of established knowledge hierarchies that impede the adoption of insights from diverse sources, such as the social sciences and humanities. STI policy can promote the emergence of consortia across disciplines or sectors that do not regularly work together to facilitate knowledge (and infrastructure) sharing (ITIF, 2022[145]). It can also provide dedicated and sustainable resources for transdisciplinary research and Open Science activities (OECD, 2020[105]). STI policy can also incentivise universities to engage in co-creation to meet the transformative goals. For example, governments can use institutional performance-based funding mechanisms to link universities' contributions to national, regional and/or local sustainability transition goals (de Silva et al., 2023[75]).

09 Cross-government coherence

How to promote cross-government coherence to co-ordinate STI-enabled transformations?

System-wide transformations unfold through interdependent processes and call for co-ordinated interventions between policy domains (i.e., STI, sectoral and horizontal policy domains), and across multiple levels of government (e.g., local, regional, national and international). Transformations that promote sustainability, inclusivity and resilience cannot be achieved or, in many cases, even chiefly driven by STI policies, although they are certainly essential. For example, targeted policies (e.g., subsidies, regulation, procurement, etc.) in domains covering energy, transport, heavy industry and agriculture are expected to do much of the heavy lifting of decarbonisation. Efforts to co-ordinate these interventions with technology phase out may also yield additional synergies. Similarly, horizontal interventions, such as education, labour and tax policies are key to providing alternatives or compensation for stakeholders impacted by phase out, as well as addressing structural inequity. These policies often benefit from vertical co-ordination to align efforts promoted by the various players and governmental agencies from different territorial levels.

The substantial scope of investments needed to facilitate transformations will necessitate buy-in from across government to co-invest in and co-manage coherent portfolios of activities. Governments can act collectively to experiment with different solutions and transformation pathways and to make strategic decisions regarding which of these should be scaled. This effort should be tailored to the characteristics of government (e.g., structure, operations, legislation, political system, etc.) that are country specific, as well as to the nature of the transformation being targeted. These considerations affect the type of policy instruments to deploy and the network of actors to involve.

STI policymakers can pursue the transformative goals through the following policy actions:

- **Actively co-ordinate and align priorities and interventions across government**: The fragmentation of state structures, often divided between government agencies with sometimes ambiguous mandates and sectoral ministries with different interests and priorities, can hinder the ability of governments to deliver the sorts of cross-cutting priorities and interventions called for by the transformative goals. Governments can deploy a range of cross-government co-ordination measures to alleviate fragmentation and better orchestrate their interventions, including shared national visions, roadmaps and missions; joint programming between research and innovation funding agencies; and strategic oversight by high-level cross-departmental committees. Some countries have also implemented structural and organisational changes, for example by merging funding agencies or ministries for STI that cover different parts of the innovation chain (Halme et al., 2019[146]). Other countries are experimenting with novel approaches, such as complementary pairings of supply-push and demand-pull interventions,[34] as well as mission-oriented innovation policies (OECD, 2023[147]).
- **Promote consistency of policy actions across levels of government**: STI policies are designed and implemented at multiple levels of government, with different traditions, path dependencies and interpretations, as well as varying degrees of autonomy (Magro, Navarro and Zabala-Iturriagagoitia, 2014[148]). This raises challenges for vertical co-ordination, especially in countries with federal systems, where policies may need to be orchestrated across multiple levels of government and, depending on the country and the policy domain, sub-national actors may be the primary decision-makers (Peters, 2018[149]).[35] A range of tools can be used to promote vertical co-ordination to support transformative change, for example, the use of co-financing arrangements to

promote effective public investment across levels of government (OECD, 2014[150]). Mapping the policy mix and stakeholder responsibilities at different governance levels can also build coherence in STI policy efforts (EEA, 2019[133]).

- **Harmonise government infrastructure and procedures to improve knowledge sharing and co-operation**: Government bodies are often constrained by their own specific rules, procedures, and internal infrastructures (e.g., intranets, data storage and sharing platforms, etc.) that are misaligned when pursuing joint actions. Governments can promote data and information sharing to identify cross-cutting regulatory and operational issues and ensure coherence between approaches (OECD, 2021[118]). Policymakers can also ensure that Open Government campaigns are based on a whole-of-government approach, which will help improve interconnections and interoperability across policy domains and government bodies, as well as build a systemic data culture (OECD, 2019[151]).
- **Streamline complex governance arrangements**: Complex governance arrangements can lead to transaction costs, the dilution of priorities, lack of leadership and blurred accountability. New governance arrangements require a clear mapping of interdependencies to understand what type of co-operation channels and joint actions would be useful to deal with specific challenges. This calls for a nuanced and strategic approach to co-ordination, which will also demand new skills, organisational capabilities, and incentives in administrations to promote and support cross- or whole-of-government co-ordination. Governments can also anchor cross-government co-ordination in national strategic frameworks by aligning a consistent package of policy and regulatory interventions with overarching national priorities (OECD, 2023[152]).

10 International STI co-ordination

How to leverage international STI co-ordination to support transformation for the public good?

Scientific discovery and technological innovation occur in an interconnected global ecosystem that draws upon collective knowledge, talent, resources and infrastructure. Academic researchers routinely co-operate and exchange across borders to advance shared scientific interests. Societal challenges, such as climate change, food security, and global health issues, are increasingly targeted in international STI co-operation, which can accelerate understanding and innovation, enhance economies of scale, strengthen incentives for investment and foster a level playing field. Sharing experiences between countries and industries can reduce individual risks, unlock synergies and efficiencies, and accelerate progress, for example, towards viable low-carbon solutions as part of sustainability transitions.

However, differing national contexts and competing interests often frustrate attempts at global collective action. With most public R&D funding allocated within national boundaries, international alignment between national strategies and programmes is notoriously difficult to achieve. National interests like domestic growth can be in tension with transnational priorities, such as protecting global common pool resources. In addition, rising geopolitical tensions and the convergence of economic and security policy agendas could undercut opportunities for cross-border knowledge exchange and technology transfer (OECD, 2023[103]). In response, dedicated collaboration arrangements, such as international climate clubs, have emerged to address free-riding challenges through mechanisms that require reciprocity (Nordhaus, 2015[153]) (OECD, IEA, 2023[154]). Individual countries are also moving towards novel collaboration approaches and more selective knowledge sharing, particularly with respect to areas of STI with national security implications.[36] This might favour the engagement of states with similar values and political interests and discourage sharing with others.

There is a significant element of justice to the inclusion of low- and middle-income countries (LMICs) in multilateral initiatives and decision-making. Many of the countries that are now most vulnerable to the consequences of climate change have contributed the least to the current situation and, to keep with international commitments, will require support to pursue alternative, less carbon intensive, routes to development (Chandy, 2023[155]). Existing international scientific networks and global connections through trade and official development assistance (ODA) present opportunities to accelerate transformative change and voluntary transfer of STI-based solutions and know-how to developing countries on mutually agreed terms. However, it has also been recognised that new approaches are required to ensure the equitable representation of LMICs in the development of international science activities (ICRI, 2021[156]). In addition, there is also value in considering and adjusting for historical legacies and other tensions that can create fear or mistrust that data and knowledge will be misused or exploited without appropriate credit given to LMIC contributors (GloPID-R, 2019[86]).

STI policymakers can pursue the transformative goals through the following policy actions:

- **Align national transformative STI priorities and co-ordinate funding for research and innovation activities to address global challenges**: Cross-country information sharing, greater harmonization of research priorities and joint funding calls among national funding agencies, private foundations and others can help address the transformative goals in a more cohesive, global manner. Such measures can help reduce duplication, enhance synergies and resilience, and maximise the impact of funding and scientific advancements. In this respect, inclusive international goals and conventions[37] can aid in securing ambitious commitments, help to destabilise the status quo (Kanger, Sovacool and Noorkõiv, 2020[110]) and align context-specific

efforts to address global challenges (Meadowcroft et al., 2021[32]). Long-term funding commitments will also provide researchers and institutions with the necessary financial security to engage in meaningful and impactful international collaboration.

- **Strengthen Open Science and knowledge sharing to improve global resilience and scale up efforts to address collective challenges**: Ideally and in line with global Open Science agendas, global knowledge sharing should aim to make STI outputs as openly available as possible, while taking into account legitimate private, public, and community interests, with a strong emphasis on equitable representation and access (OECD, 2021[157]).[38] Despite notable progress in some areas, several challenges persist, such as issues posed by publishing business models and evaluation and incentive frameworks that do not appropriately value efforts to make data and software Findable, Accessible, Interoperable and Reusable (FAIR) (Wilkinson et al., 2016[158]). Various policy actions may be warranted to improve the openness of different scientific outputs across different disciplines, while also ensuring that private, public and community interests, including national security, IPR, privacy and personal data are protected.[39] For example, a review of mechanisms, legal frameworks and skills may be useful for enhancing sharing or pooling information, and data on voluntary and mutually agreed terms (OECD, 2015[159]).
- **Safeguard research integrity and security of the global research system**: There are growing concerns over safeguarding national and economic security and protecting freedom of enquiry. Many governments have developed training modules, guidelines and checklists to increase awareness of and provide guidance to the Academic community on research security and integrity, frequently accompanied by policies and measures to mitigate these risks.[40] These should be proportionate and based on sound risk identification and assessments, as not every research institution or research project will face the same level or type of risk (OECD, 2022[28]).
- **Scale up inclusive multilateral partnerships to respond effectively and equitably to global challenges**: Efforts to strengthen the capabilities of developing countries to engage as equal partners in global collaboration and decision-making are increasingly important. Capacity building efforts should align with recipient countries' transformation needs and research capacities, and target the development of necessary infrastructures and collaborative platforms (COVID CIRCLE, 2021[160]) (OECD, 2022[161]). More generally, countries with similar contexts and challenges stand to benefit from the integration of resources and activities around common priorities (OECD, 2023[162]). To date, this has been challenged by attaining agreement among funders with diverse priorities and resources (OECD, 2023[143]). Hybrid funding mechanisms could be used to combine funding and in-kind support from a diversity of actors. It will also be important for the global community to support multilateral and club-based STI collaborations that include or are driven by representatives of the Global South.
- **Foster international market conditions that enhance the competitiveness and equitable access to emerging STI-based solutions**: Legislation, regulatory frameworks, standards and soft law influence the function of domestic markets and STI systems, e.g., the flow of goods, ideas, people and capital, and can accelerate the deployment of transformative innovations across borders. However, the effective use of these tools can be impeded by challenges to co-ordination across governance levels (sub-national, national and supra-national), between national policy domains, and with industry. Many are also often deployed by actors outside conventional STI and STI policy mandates.[41] Centers of government can play an intermediary role by facilitating collaboration between STI policymakers, sectoral policy domains (e.g., regulation), and horizontal policy domains (e.g., trade and investment).[42] These same actors will then have invaluable insights to feed into international co-operation or diplomacy efforts.

4 Further guidance and next steps

The Transformative Agenda provides high-level guidance to support policymakers and other relevant stakeholders in formulating and implementing reforms to accelerate and scale-up positive change.

The Transformative Agenda includes comprehensive coverage of how STI activities and policy can hasten economic and societal transformations in the face of mounting global challenges. It highlights multiple points of entry and a range of key messages that readers might apply based on their roles and responsibilities in STI and STI policy systems. For high-level decision-makers, the implications and interdependencies of the three transformative goals are a critical consideration, as well as what they might mean for future STI mandates. Conversely, policymakers involved in programme design and implementation may find applicable insights in sections on specific STI policy areas, such as international STI relations or skills and capabilities. The Transformative Agenda may also be relevant for other stakeholders, including policymakers in other policy domains and stakeholders who are active in STI systems, such as researchers in the natural and social sciences, public research organisations and industry, as well as entrepreneurs, civil society organisations and citizens.

Putting reforms into practice will require policymakers to translate them to specific STI policy area and sectoral contexts, typically (though not only) at the national level. In this regard, an important deliverable of the OECD's S&T Policy 2025 project is concrete policy guidance that aims to help policymakers reappraise, and if applicable, reform their STI policies to better contribute to sustainability, inclusion, resilience and security. Accordingly, sections of the Transformative Agenda that focus on specific STI policy areas will be supplemented by two additional forms of guidance:

- **Modular policy guidance** that discuss proposed key actions, potential implementation pathways and challenges posed by the status quo for the Transformative Agenda's ten STI policy areas.
- **Key policy challenge 'toolkits'** that provide step-by-step, interactive online tools for users to translate specific STI policy challenges into feasible and context-specific actions.

Modular policy guidance

Modular guidance, provided through a combination of published and interactive digital content, will introduce key considerations, challenges, and drivers for change in each of the ten **policy areas**. Guidance will provide policymakers and other stakeholders with the necessary background information to support their use of policy toolkits to develop targeted and context-specific actions. Each module will use a gap analysis to unpack the **key policy actions** outlined in the Transformative Agenda. Analysis contrasts the general 'status quo' for each policy area against the ideal vision required to support the transformative goals. Key (endogenous and exogenous) factors that might be influencing the STI system are also considered.

Intended users of the modular guidance are those who have a responsibility for or a direct stake in specific policy areas. This could include policymakers, academics and public research organisations, industry associations, and non-government organisations, among others.

Key policy challenge toolkits

The policy 'toolkits' are meant to serve as a functional resource for policymakers and other stakeholders to consider key challenges identified in each of the ten STI policy areas and potential actions that might be taken to address them. The toolkits will take users through a sequence of steps to support them in **thinking systematically and iteratively about a targeted problem and a corresponding desirable future vision; the current situation and related challenges and enabling conditions; potential sequences of actions; and how progress might be measured and monitored**. These resources will be made available through an online playbook to allow users to work with interactive elements, such as prefilled canvases and live data from the STIP Compass and STI Scoreboard platforms.

Toolkits will be tailored for use by subject matter experts, such as mid- and lower-level officials, who are responsible for policy design, planning and implementation in specific STI policy areas. The toolkits are intended to complement rather than substitute officials' existing processes to formulate policy portfolios. For example, structured canvases may be useful to map and discuss wider system elements, which may not otherwise be considered, through the engagement of stakeholders who are not conventionally included in policymaking processes. In this respect, the toolkits can be a helpful resource to engage a range of contributors, from senior policymakers to citizens, in a workshop setting. Toolkits might also be deployed by individuals or small teams to organise their thinking on specific policy challenges.

Future CSTP activities

The CSTP will follow up on the Transformative Agenda in its future activities. Related projects will aim to use peer learning methods for countries to exchange on their experiments in formulating, designing and implementing STI policies targeting transformative change. Projects will incorporate co-creation and sense-making processes while codifying insights into improved policy guidance.[43] A new series of OECD innovation policy country reviews on transformative STI policies could also be inaugurated.

Figure 4.1 summarises the next steps in supporting countries to put the Transformative Agenda into STI policy practice.

Figure 4.1. Next steps in supporting countries' efforts to implement the Transformative Agenda

Endnotes

[1] Analysis suggests that the COVID-19 pandemic has enabled the largest growth of between-country income inequality in thirty years. From 2019-2020 it was projected to rise 4.4%, up from the pre-pandemic forecast of a decline of 0.8%.

[2] These are among a range of megatrends impacting societies that also include ageing populations, productivity slowdown, growing environmental degradation, and growing political and cultural polarisation in many societies.

[3] The triple planetary crisis refers to interrelated threats posed by climate change, pollution and biodiversity loss (UNFCCC, 2022[198]). See other related OECD works, such as publications developed through the Resource Efficiency and Circular Economy (RE-CIRCLE) project (https://www.oecd.org/environment/waste/recircle.htm), the Horizontal Project on Climate and Economic Resilience (NET Zero+) (https://www.oecd.org/climate-change/net-zero-resilience/) and the OECD Roundtable on Financing Water (https://www.oecd.org/water/roundtable-on-financing-water.htm), among others. In addition, the organisation manages several databases, such as the International Programme for Action on Climate (IPAC) (https://www.oecd.org/climate-action/ipac/).

[4] Definitions of transformative change refer to "a radical permanent qualitative change in the subject being transformed, so that the subject when transformed has very different properties and behaves or operates in a different way" (HM Treasury, 2022, p. 122[68]); and "a major change in the structure of the economy brought about by deliberate policy efforts aimed at supporting specific long-term environmental, social, economic or other goals, or in response to climate change and other relevant long-term trends" (Ministry of Business, Innovation & Employment,, 2023, p. 1[203]). In this Transformative Agenda, the transformation concept is used as an umbrella term to refer to change that involves the reconfiguration of a system so that it behaves in a qualitatively different way (HM Treasury, 2022[68]). It is a process of structural change involving changes in the component parts of a system and the pattern of interactions between them. It is distinguished from incremental change, which is limited to adjustments within a system that do not fundamentally alter its essence or integrity (Schumer et al., 2022[66]). Societies and economies have experienced many previous transformations, for example, the change from sailing ships to steamships, from traditional factories to mass production, and from horse-drawn carriages to automobiles (Geels and Schot, 2007[202]).

[5] Decades of investment into fundamental research on mRNA largely facilitated the expedited development and deployment of mRNA-based vaccines during the COVID-19 pandemic response (Dolgin, 2021[175]). Further, mRNA vaccine platforms build on established vaccine technologies and have the potential to accelerate development and manufacturing processes without compromising on safety (Pardi et al., 2018[176]).

[6] Many STI policy instruments are implicated in phase-out, but this is often as a result of them being withdrawn from supporting harmful technologies and activities.

[7] The OECD "*Framework for the Anticipatory Governance of Emerging Technologies*" (OECD, 2024[29]) describes these as 'foundational values' and offers the following examples: **Respecting human rights,**

including protections of human dignity, and basic liberties such as freedom of thought, the right to privacy, and autonomy; Promoting **democratic values**, including the rule of law, equality under law, representation and participation in public life and debate, accountability, procedural justice and the public interest; Promoting **sustainable development,** including the responsibility to protect biodiversity and ecosystems and address climate change while promoting human well-being; Encouraging **equity and inclusion,** recognising diversity and accessibility in its many forms, of ensuring fair treatment and full participation of individuals or groups that are vulnerable and/or have been historically excluded or marginalized, and providing fair access to the benefits of innovation. It should be understood both in terms of outcome, i.e. striving to ensure the availability of technology, as well as process, i.e. expanding who participates in technological development. See OECD (2024[29]).

[8] For example, nature-based solutions (NbS) aid in addressing societal challenges through actions that proactively protect, restore, and manage natural ecosystems sustainably. Such activities have a dual focus to benefit both the natural environment and human well-being (IUCN, 2020[190]). The concept emerged in response to the UN Framework Convention on Climate Change (UNFCCC) to facilitate the ability of the conservation community to contribute to major global challenges, such as food security and disaster risk reduction (IUCN, 2012[188]). Following the diverse application of the term, the International Union for Conservation of Nature introduced the IUCN Global Standard for NbS to prevent misuse and loss of stakeholder trust, and support the development of ambitious and effective projects (IUCN, 2020[189]).

[9] Such dynamics are familiar to STI policy practitioners, since the advance and diffusion of new technologies follow similar S-shaped curve patterns, characterised by learning by doing, increasing returns to scale, path dependencies, and diminishing returns, among other dynamics.

[10] Transitioning from established ways of doing things is often challenged by politics and uneven power dynamics. Dominant stakeholders generally have vested interests in maintaining established industries, technologies and practices and are often in a position to influence structural conditions, e.g., regulation, or mask the full costs of the status quo (Johnstone, Stirling and Sovacool, 2017[164]). At the same time, the political domain is also a consequential site for civil discourse and an avenue for the public to influence which issues and ideas are adopted and institutionalised and which are discarded (Meadowcroft, 2009[163]).

[11] The passing of the Montreal Protocol on Substances that Deplete the Ozone Layer is a well-known example of international efforts to phase out harmful technologies and practices. While the 1987 signing of the treaty marks the formal breakdown and phase out of established ways of doing things, it is now recognised that destabilisation was first precipitated by a series of scientific findings, beginning in 1974 (Dugard, 1997[179]). In addition, phase out efforts have continued and been expanded in scope since the treaty came into force, most recently in 2016 with the Kigali Amendment, which seeks to scale down the use of hydrofluorocarbons (UNEP, 2020[180]).

[12] For example, STI policies could also explore options for setting ‘posteriorities’, i.e. research and technology activities that would be identified to receive diminished support on account of their contributions to global problems.

[13] History is replete with examples of sociotechnical transitions beginning with disruptive technology innovations in niches that cascaded upwards through tipping points to society-wide transformation. These include the move from horse drawn to motorised road transport, electrification, the build out of sewage and water supply systems, and the emergence of digital commerce (Meadowcroft and Rosenbloom, 2023[39]). More recent and widely cited examples include rapid decarbonisation of the UK’s power sector and the widespread adoption of electric vehicles in Norway. In both cases, a mix of measures, including R&D

funding, investment in clean technologies and regulatory market reforms, laid the groundwork that brought the system to a 'state of criticality' for carbon pricing (and other taxes and subsidies) to activate tipping points (EEIST, 2022[126]). Public policies therefore created the spark for the initiation of positive tipping points and the conditions for them to cascade through sociotechnical systems (Systemiq, University of Exeter and Bezos Earth Foundation, 2023[42]).

[14] For example, in its Special Report on Clean Energy Innovation, the IEA outlines four pillars – resource push, knowledge management, market pull, and socio-political support – and corresponding policy levers to facilitate the translation of research into technological change in the energy system (IEA, 2020[178]).

[15] For example, the 2021 OECD Recommendation for Agile Regulatory Governance acknowledges the need for more holistic, inclusive, adaptive and co-ordinated governance models to enhance systemic resilience (OECD, 2021[118]).

[16] Foreign direct investment (FDI) can generate knowledge and technology spillovers that promote transformations in local economies The OECD FDI Qualities Indicators show that sectors receiving more FDI tend to have higher R&D intensity levels and foreign-owned firms are on average more innovative and technology-intensive than their domestic counterparts (OECD, 2022[165]).

[17] Funders operating in research areas commonly involved in crisis response have made use of funnel approaches where draft priorities are informed through environmental scanning, international and domestic science advice structures, and targeted outreach across policy domains and other funding agencies (OECD, 2023[72]). Research areas can then be prioritised based on previous funding and current need, policy relevance, research gaps, scientific validity, and feedback from the broader research community.

[18] The Declaration of Research Assessment (DORA) was established in 2012 and has since spurred a movement to reform research evaluation and assessment practices (DORA, n.d.[177]). In some respects, the COVID-19 pandemic response renewed these efforts due to calls for institutions to redefine expectations for science productivity and to ensure the transparent evolution of evaluation frameworks.

[19] The OECD (2021[76]) defines high-risk, high-reward research as research that 1) strives to understand or support solutions to ambitious scientific, technological, or societal challenges; 2) strives to cross scientific, technological, or societal paradigms in a revolutionary way; 3) involves a high degree of novelty; and 4) carries a high risk of not realising its full ambition as well as the potential for high, transformational impact on a scientific, technological, or societal challenge.

[20] Among the key factors that promote conservatism in research are tenure, promotion, and advancement policies at research institutes. There are powerful incentives in the current system for researchers, especially early-career researchers, to be conservative in their research in order to be more certain of securing the publication outputs against which they will be assessed. Promoting HRHR research requires a change in the human resource policies of research institutes and in research assessment more broadly (OECD, 2021[76]).

[21] Governments could also redirect some of their R&D tax credits towards greener activities. There are various ways this might be achieved in practice, including targeting tax credits towards large-scale infrastructure required for technology deployment (e.g., carbon capture, utilisation and storage; electric vehicle charging; hydrogen) and investment in new low carbon machinery or equipment, among others (Beck, 2020[194])

[22] The IEA estimates that at least USD 90 Billion of public funding needs to be raised by 2026 to complete a portfolio of demonstration projects for technologies that could be commercially ready by 2030 and contribute to achieving net zero emissions by mid-century (IEA, 2022[174]).

[23] For example, in the green transition, challenges for private investors include insufficient profitability compared to investments with similar risk profiles; difficulty assessing risks owing to information asymmetries between innovators and investors; lack of awareness and uncertainty around government priorities and regulations; and challenges in meeting 'internal rate of return' requirements or 'return on equity' thresholds. These imperfections in capital markets limit the amount of private capital available for low-carbon technologies (Cervantes et al., 2023[70]).

[24] While organisational or dynamic capabilities lack a universally agreed definition, in this context they can be taken to refer to strategic routines or processes that might be in place in an organisation to improve its ability to 'integrate, build and reconfigure internal and external competencies to address rapidly changing environments' (Teece, Pisano and Shuen, 1997, p. 516[182]) (Bleady, Ali and Ibrahim, 2018[183]).

[25] Micro-credentials represent a potentially disruptive innovation in the education sector. As such, it will be important for the STI system to advance the underlying evidence base as related experiments are deployed. For example, little is currently known about how micro-credential programmes might impact higher education institutions and the roles and responsibilities of different actors, including policymakers in determining qualification criteria and standards.

[26] This policy action aligns with and expands on the 2019 OECD Declaration on Public Sector Innovation (OECD, 2019[196]). The Declaration was introduced to legitimise innovation as a central strategic function of the public sector and to provide recommendations to support governments and policymakers in taking more deliberate approaches to innovation management. A variety of avenues are outlined to assist public sector organisations across five priority areas: embracing and enhancing innovation; encouraging and equipping all public servants to innovate; cultivating new partnerships and involving different voices; supporting exploration, iteration and testing; and diffusing lessons and sharing practices.

[27] For the sake of practicality, this section focuses primarily on more tangible factors, i.e., infrastructure, standards and regulation, and tools intended to augment commercial and financial markets. Other structural conditions, such as labour policy and ethics are covered elsewhere in other STI policy areas.

[28] Carbon pricing is, in principle, a way to make polluters pay for their greenhouse gas emissions, for example, through a carbon tax or a cap-and-trade system. Carbon pricing changes the relative costs and benefits of competing technologies, which can lead to the development of new technologies and processes that are more energy-efficient and environmentally friendly. However, measures like carbon taxes are politically unpopular and are currently set at sub-optimal levels.

[29] For example, approaches like technology assessment and foresight have an established track record of providing decision-makers with strategic intelligence on emerging technologies. They provide open and inclusive processes to better align innovation and regulation trajectories with societal goals, taking into account possible ethical and societal aspects and potential impacts and risks.

[30] For instance, ongoing debates on the use of 'science for policy' call for scientists to become better communicators and to consider policy makers as end users of scientific knowledge (Boswell and Smith,

2017[192]) (Edler, Karaulova and Barker, 2022[193]). Another example relates to the limited use of evaluation findings in policy making (Amanatidou et al., 2014[195]), which can hamper policy adaptation and agility.

[31] International surveys suggest that globally, public trust in science and scientists rose during the COVID-19 pandemic (Gallup, 2020[168]). However, more recent country-specific data indicate that in some instances, this trend has reversed with trust declining below pre-pandemic levels (Pew Research Center, 2022[170]), while in others, attitudes have become more polarised (Fonseca et al., 2023[171]). When compared against public trust in other prominent actors, such as journalists and politicians, results could indicate a broader societal trend of declining public trust in institutions (Ishmael-Perkins et al., 2023[172]). In this case, scientists and medical professionals remain among the most trusted actors (Environics Institute, 2023[169]).

[32] Analysis of the demographic characteristics of citizen science participants reveals general patterns of the overrepresentation of highly educated, high-income individuals (Geoghegan et al., 2016[166]).

[33] Insights from behavioural science can be useful for the development of citizen science activities in several respects. Some of these include anticipating potentially unintended effects of activity design, understanding how structural inequalities can contribute to variations in the expectations of different population groups, and supporting scientists and public participants in probing into how their experiences and personal characteristics influence views on specific topics (Hallsworth, 2023[187]).

[34] For instance, some joint agency initiatives mix both technology push and market pull instruments to provide support to new solutions along all stages of the innovation process, e.g. by combining funding mechanisms with public procurement and the removal of legal barriers for the market uptake of new solutions among users (Larrue, 2021[26]).

[35] Multi-level governance reforms are generally conducted by central governments, but they can also be partially driven by sub-national levels. Accordingly, reforms emerging at other government levels should be understood and managed efficiently in order to account for mutual dependencies in relations (OECD, 2017[191]).

[36] For example, in the United States, the National Science Foundation's Global Centers program supports partnerships between the US and two or more partner countries. The program is meant to support multidisciplinary research that can only be achieved through the development of international partnerships that unite complementary areas of expertise and access to unique capabilities and resources. Participating funding agencies are based in Canada, Japan, Republic of Korea, Finland and the United Kingdom (NSF, 2024[197]).

[37] Global diplomacy efforts on climate change date back to 1992 with the ratification of the UN Framework Convention on Climate Change (UNFCCC), This accord established the annual Conference of the Parties (COP) forum to support global exchange and discussion, ultimately producing the Kyoto Protocol and Paris Agreement (Maizland, 2023[181]). Since negotiation of the initial Paris accord, many of the 195 signatory countries have strengthened their commitment to reduce greenhouse gas emissions and support the adaptation of emerging and disproportionately impacted economies.

[38] Various international initiatives have advanced the global Open Science agenda in recent years. For example, in 2021, UNESCO introduced the organisation's Recommendation on Open Science, which outlines seven areas for action from promoting a common understanding of open science to improving international and multi-stakeholder co-operation to reduce digital, technological and knowledge gaps

(UNESCO, 2021[184]). Additionally, OpenAIRE has been in place since 2009 to support the widespread implementation of Open Access in Europe (OpenAIRE, n.d.[185]).

[39] The revised OECD recommendation on access to research data from public funding identifies seven key areas of focus, including data governance, technical standards and practices, and incentives and rewards (OECD, 2021[157]) (OECD, 2020[173]).Similarly, the OECD Recommendation on Enhancing Access to and Sharing of Data, which is broader in scope, sets out general principles and policy guidance to support governments in maximising the benefits of improving data accessibility, while protecting the rights of individuals and organisations (OECD, 2019[201]).

[40] The OECD maintains a collection of such policies in the EC-OECD STIP Compass, see https://stip.oecd.org/stip/research-security-portal.

[41] Over the last decade, attention to the security implications of foreign investment has reached an unprecedented level, with many governments introducing new or adjusting existing policies in response to disruptions triggered by the COVID-19 pandemic and Russia's war of aggression against Ukraine (OECD, 2023[186]). In many of the countries with related instruments in place, these mechanisms cover large parts of the economy or, at minimum, multiple sectors of strategic importance to economic competitiveness and/or the strategic autonomy of socio-economic systems. For example, since the mid-2000s, there has been a diversification and broadening of the focus of related policies to include sectors such as critical infrastructure, advanced technologies, health infrastructure, and biotechnologies. Further, investment screening mechanisms, which require the review of specific transactions defined by associated criteria, have become the most common instrument used to manage risks associated with foreign investment.

[42] There are important feedback loops between standards and regulation, international trade and investment, and technological innovation. International standards and certifications can be key enablers of international trade and investment; however, domestic alignment is necessary to encourage responsible business conduct and improve the realisation of equitable outcomes related to sustainability and economic inclusion (OECD, 2022[165]). At the same time, opportunities afforded by trade, such as access to new markets or supply chains and increased domestic competition, are essential to innovation (Blind, 2023[167]).

[43] These activities will build off an initial 2024 pilot project with Thailand to test and experiment with the module guidance for several STI policy areas.

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Annex: S&T Policy 2025 Advisory Board and Steering Group Membership

Table A.1. S&T Policy 2025 Advisory Board Membership

Country	Name	Affiliation
AUT	Matthias Weber	Head of Center for Innovation Systems and Policy, AIT Austrian Institute of Technology GmbH
BEL	Michel Goldman	Founder of the Institute for Interdisciplinary Innovation in healthcare (I3h) at the Université libre de Bruxelles; Editor-in-Chief of *Frontiers in Medicine*
CAD	Catherine Beaudry	Full Professor, Department of Mathematical and Industrial Engineering, Polytechnique Montréal; Canada Research Chair in Management and Economics of Innovation; Director, Partnership for the Organisation of Innovation and New Technologies (4POINT0)
CAD	James Meadowcroft	Chancellor's Professor, Department of Political Science and the School of Public Policy and Administration, Carleton University; Research Director, Transition Accelerator
CHL	Alexis M. Kalergis	Full Professor and Director Millennium Institute on Immunology and Immunotherapy, Pontificia Universidad Católica de Chile
FIN	Paula Kivimaa	Research Professor, Climate and Society & Academy of Finland; Research Fellow, Finnish Environment Institute SYKE, Climate Change Programme; Senior Research Fellow, Science Policy Research Unit, University of Sussex
ITA	Alessandra Faggian	Professor of Applied Economics, Director of Social Sciences and Vice Provost for Research at the Gran Sasso Science Institute
JPN	Mitsunobu Kano	Professor and Vice Executive Director of Okayama University Graduate School of Interdisciplinary Science and Engineering in Health Systems
KOR	Myong Hwa Lee	Research fellow and Head of the National R&D Research Office at the Science and Technology Policy Institute
NLD	Marko Hekkert	Full professor of Dynamics of Innovation Systems at Utrecht University, Director of the Copernicus Institute of Sustainable Development
POL	Anna Visvizi	Associate professor, Head of the International Political Economy Department, SGH Warsaw School of Economics
SWE	Sylvia Schwaag Serger	Professor of Research Policy at Lund University School of Economics and Management, Member of Swedish Prime Minister Innovation Council
USA	David Guston	Foundation Professor; Director, School for the Future of Innovation in Society; Associate Vice Provost for Discovery, Engagement and Outcomes, Global Futures Laboratory, Arizona State

Table A.2. S&T Policy 2025 Steering Group Membership

Country	Name	Affiliation
AUT	Christian Naczinsky	Head of Department, EU and OECD Research Policy, Ministry of Education, Science and Research
CAD	Daniel Dufour	Director General, Natural Resources Canada
CHE	Patrick Vock	Co-ordinator for Multilateral Affairs, State Secretariat for Education, Research and Innovation
EC	Alexandr Hobza	Chief Economist, Director General for Research and Innovation, European Commission
ESP	Cecilia Cabello-Valdes	Policy Officer, Director General for Research and Innovation, European Commission
FIN	Kirsti Vilen	Ministerial Advisor, Ministry of Economic Affairs and Employment
FRA	Patrick Monfray	Emeritus Research Director, Institut Pierre Simon Laplace
GBR	Amanda Collis	Executive Director, Research Strategy, UK Research and Innovation
JPN	Hidetoshi Kotera	Professor Emeritus, Kyoto University, and Technical Advisor to Science and Technology Policy Bureau, Ministry of Education, Culture, Sports, Science and Technology
KOR	Yongsuk Jang	Senior Research Fellow, Science and Technology Policy Institute
PRT	Luis Melo	Professor, Dept of Physics, Technical University of Lisbon, Portugal
SWE	Göran Marklund	Deputy Director General and Head of Operational Development Division, VINNOVA

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