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Navigating Green and Digital Transitions: Five Imperatives for Effective STI Policy

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This paper discusses five innovation policy imperatives critical to achieving green and digital transitions: coordinated government, stakeholder engagement, policy agility and experimentation, directionality and support for breakthrough innovation. The paper provides policy examples from Germany, based on the *OECD Review of Innovation Policy: Germany,* and other countries to illustrate in what ways countries have addressed these imperatives. Overall, the quality and scale of these policy responses need to increase if transitions are to succeed. Open questions for future policy research are also highlighted.

Keywords: STI policy, innovation policy, green transition, digital transition, digital transformation, governance, stakeholder engagement, agile policy, policy experimentation, directionality, breakthrough innovation, country policy examples, Germany

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Acronyms and abbreviations

AI	Artificial Intelligence
BMBF	Federal Ministry of Education and Research, Germany
BMWi	Federal Ministry for Economic Affairs and Energy, Germany
BMWK	Federal Ministry for Economic Affairs and Climate Action, Germany
DARPA	US Defense Advanced Research Projects Agency
DFG	German Research Foundation
EEA	European Environmental Agency
EFI	Commission of Experts for Research and Innovation, Germany
EU	European Union
EUR	Euro
GDP	Gross domestic product
HTS	High-Tech Strategy
IEA	International Energy Agency
MOIPs	Mission-oriented policies
PRO	Public research organisation
R&D	Research and development
R&I	Research and innovation
SDGs	United Nations' Sustainable Development Goals
SME	Small and medium-sized enterprise
SPRIND	Federal Agency for Disruptive Innovation
S&T	Science and innovation
STI	Science, technology and innovation
USD	United States dollar
VC	Venture capital

Executive Summary

STI policy imperatives for the green and digital transitions?

The green and digital transitions imply a shift towards a net-zero, environmentally friendly economy and society that leverages digital technologies to achieve shared socio-economic objectives of inclusiveness, competitiveness, resilience and well-being. Science, Technology and Innovation (STI) are critical to achieve those objectives.

Five STI policy imperatives are needed to pursue long-term transition objectives while confronting shocks and structural and current socioeconomic challenges, including implications of geopolitical tensions, rising inequalities, population ageing and unemployment.

These mutually reinforcing policy imperatives are:

1. Coordinated government – the integration and alignment of policies across transnational, national, and sub-national levels of government and different line ministries and agencies.
2. Stakeholder engagement – governments actively involving citizens, research institutions and industry to develop and legitimate shared visions and implement collaborative action plans.
3. Policy agility and experimentation – the ability to swiftly respond and adapt to changing circumstances in the design and implementation of policies.
4. Directionality – intentional efforts to shape the trajectory and focus of socio-technical change towards specific societal objectives.
5. Support for breakthrough innovation – policies aimed at facilitating the development and adoption of disruptive innovations in support of transitions.

While countries have addressed the policy imperatives, the quality of the solutions needs to be improved and their scale expanded to achieve impact.

Imperative 1: Coordinated government

The transition needs coordinated government efforts to align policy interventions across various areas such as infrastructure and investment in support of STI for transitions, and to address uneven geographic impacts of transitions by coordinating from local to national levels.

Transnational governmental coordination is needed to share perspectives on desired global futures and act jointly, including to establish international standards.

Coordinated governance is difficult because it requires that different policy areas and multiple levels of government are aligned, which can be hindered by siloed government organisation, communication gaps, political dynamics, and capacity constraints.

An example of national-local coordination on green-related goals are Climate City Contracts – action and investments plans signed between cities and national governments co-created with citizens and city stakeholders to achieve climate neutrality by 2030, implemented as part of the EU Mission on Climate Neutral Cities. Mission-oriented policy approaches are also progressively integrating coordinated actions across policy domains and engaging experts, industry players, and citizens.

Imperative 2: Stakeholder engagement

In the context of the green and digital transitions, stakeholder engagement is essential to:

1. build a collective understanding of the complexities of transitions and the role of STI and its policies in this context, and enhance trust in government,
2. improve decision-making on directions to take and shape STI system outcomes inclusively, and
3. coordinate action at scale to lead to transitions.

Engagement in policy processes is difficult as stakeholders have diverse incentives, and engagement in joint action requires reaching consensus, based on costly processes to be effective.

An example is the project “Attitudes to new transport technologies” (2021-2022) of the Norwegian Board of Technology which involved citizens in developing future transportation technology scenarios, such as self-driving cars and shared mobility.

Imperative 3: Agility and experimentation in policy

Transitions are complex and uncertain processes that require adaptive and flexible approaches. Policy experimentation allows for testing and learning from new ideas and interventions, essential in a new context. Without agility that enables policy to respond quickly, policy may fail to keep pace with technological change, adequately protect consumers, or exploit emerging opportunities.

Implementing agility and experimentation in policy requires modifying highly regulated and bureaucratised processes in the public administration, set up to manage public funding responsibly. The transformation requires the public administration embraces agile and entrepreneurial policy approaches and leverages new digital tools to gather and analyse data. Management that actively promotes and incentivises these policy approaches within the public administration is needed.

Many countries have paid more attention to foresight studies in the STI policy arena to better prepare their policies to future trends and enhanced investments in data gathering and analytics for better data-based policy evidence.

Imperative 4: Directionality

Directionality is needed for transitions as they require coordinating complex transformations, like deploying wind energy, which requires regulatory involvement and incentives, and action by industry and research institutions.

While directionality can align with market-based approaches and does not require “picking winners”, constraints emerge when future technologies necessitate choices regarding the types of public infrastructure investments to pursue.

The most important development to implement directionality in STI policy has been the implementation of mission-oriented policies (MOIPs) across EU countries.[1] An OECD report gathered 83 net-zero missions in 30 major MOIP initiatives were in place in 20 countries in 2022 (OECD, 2023[2]).

The success of missions depends also on their quality, including aligning rather than simply repackaging programmes to meet goals.

Imperative 5: Support for breakthrough innovation

Breakthrough innovations are necessary to address societal transition goals. This is illustrated by the need for technological solutions to decarbonise the global economy and business innovations to guarantee future competitiveness and shape societally desired digital futures.

Policy support requires greater willingness to take risks and experiment in supporting the supply side –the production of breakthrough research and inventions – while also attending to the demand side –the deployment and diffusion of those breakthroughs.

An example is the creation of SPRIND in Germany, which aims to identify, develop and help scale innovations that have the potential to lead to radical or breakthrough innovation.

What is the next frontier for policy and research?

Reaching the policy imperatives to support transitions also requires countries establish a shared flexible vision of their desired future.

More concrete policy guidance on setting up legitimate joint goals and orchestrating actions across various stakeholders is much needed.

1 Introduction

Digitalisation and the shift towards greener economic systems are driving significant and disruptive changes across the OECD. Digital technologies are continuously transforming what and how economies produce and operate, with advances in microelectronics, data, and digital. Simultaneously, the societal push for carbon neutrality requires the rapid development and commercialisation of science, technology and innovation (STI) solutions for climate change mitigation and adaptation.

What do these transition dynamics imply for conducting STI policy today? The paper discusses five policy imperatives for STI policy in the context of the green and digital transitions. These are coordinated government, stakeholder engagement, policy agility and experimentation, directionality, and support for breakthrough innovation. Specific policy examples from across the OECD and specifically Germany are provided.

The paper draws on the literature on current and past transitions and complements this with international policy experiences and examples from Germany from the *OECD Review of Innovation Policy: Germany* (OECD, 2022[1]). Evidence gathering for the Review was enriched with expert interviews, and international workshops on "Rethinking innovation policy in times of transitions" (December 2022), "STI policy in a complex global context" (June 2022), and "Strategic approaches for future transitions: How to improve effective collaborations in policymaking?" (April 2022).

This paper is part of the 2021-22 OECD-TIP project "Supporting co-creation in collaborative transitions: Exploring new tools and approaches" and was developed in connection with the *OECD Review of Innovation Policy: Germany* (OECD, 2022[1]). The document has a companion paper that applies natural language processing techniques to explore whether OECD countries' STI strategies reflect new transition policy ambitions and aim to apply these new policy imperatives (Einhoff and Paunov, Forthcoming[3]).

The remainder of the paper is structured as follows. Section II provides a brief overview of the five imperatives and their interconnections. Sections III, IV and V discuss the five priorities for STI policies for transitions, with section III focusing on joint governance, section IV focusing on policy agility and experimentation and section V focusing on policy directionality and efforts to foster breakthrough innovation. Section VI concludes by discussing the next goals for STI policy and outlining open questions.

Infographic 1.1. Innovation policy imperatives for transitions

2 Overview on five policy imperatives and their interconnection

2.1 Definition of and relationships between five STI policy imperatives

From the perspective of STI policies after 1945, innovation policies in the context of the current digital and green transitions have been termed "third generation policies" that aim at addressing 'wicked' problems (i.e. policy problems that are particularly difficult to solve due to a number of characteristics (Schot and Steinmuller, (Schot and Steinmueller, 2018[4]).

The third generation STI policy funding paradigm contrasts with the first and second generation. The first generation – for which Vannevar Bush's report (Bush, 1945[5]) is the manifesto – focused on 'basic' research, delegating the governance of science to the scientists, and relying on the idea that 'science push' would eventually generate the right innovations and other benefits for society. In other words, there was no major concern about "good" or "bad" science or innovation. The second generation was partly triggered by the OECD's invention of 'science policy' in the 1960s, assuming greater political control of science, and demanding a social return from research through innovation and economic growth. 'Demand pull' is identified as playing a major role in the diffusion of the benefits of research. This evolved into 'national innovation systems' thinking, seeing innovation as co-produced, and overall performance as dependent on involving society. The main focus was on innovation serving economic growth and consequent contributions to societal goals. There was little concern about "bad" innovations or negative outcomes of innovation processes. More was regarded as better.

In this "third generation" period, new policy imperatives for policy emerge, which are: joint governance, referring to both (i) effective coordination across different levels of government but also (ii) stakeholder engagement. Other goals consist in (iii) building more flexibility to respond to the rocky road ahead, (iv) setting targets in more precise ways and (v) enacting transformations by providing opportunities for the breakthrough innovations that will increase the pace of the transformations (Table 2.2). While they were helpful in past STI policy models, they now become essential as outlined in (Table 2.1)

Table 2.1) summarises key characteristics of this third generation compared to the previous two generations of STI funding. There are important differences emerging from the perspective of transitions that radically expand the scope of STI policies towards ambitiously supporting transitions. This, in turn, requires a more coordinated governance and new organisational approaches towards joint engagement to implement changes required if those socio-economic goals are to be reached.

Figure 2.1 provides an overview of the goals of each of those policy imperatives relevant to the transition context and why they are necessary for successful transitions. Jointly the imperatives provide for setting societal goals and focus on implementing transitions by providing for the capacity for swift responses and powerful technological solutions.

In turn, those five policy imperatives are interconnected and reinforce each other in important ways (Arnold et al., Forthcoming[6]). Figure 2.2 illustrates the most dominant of those connections. For instance, joint governance (imperatives 1 and 2) is needed to set shared policy directions (imperative 4) and enables synchronised policy action to support breakthrough innovation (imperative 5).

The shocks and challenges OECD countries face require those five policy imperatives to resist deviations to respond to short-term objectives where these do not support long-term transition goals. The risks of short-termism are high in view of multiple shocks, including the COVID-19 crisis and the Ukraine war, high levels of inequalities and polarization, structural challenges (incl. public debt levels and population ageing) and economic challenges (incl. high inflation rates affecting households purchasing power and unemployment). At the same time, extreme weather events such as droughts, floods, wildfires and heatwaves may increase political commitment and policy efforts to curb climate change while high prices for energy imports may spur investments in renewables. Incidences of societal unrest has increased debates and regulatory concerns over social media regulations in the digital world, such as dealing with deep fakes that may cause harm if unaddressed.

Table 2.1. Characteristics of three STI policy paradigm changes

Characteristics	First Generation	Second Generation	Third Generation
External driver of change	Growth and destructive power of science in World War II	Refocusing of state research on technology, innovation, and industrial growth	Societal challenges posed by the digital transition and increased concern over the lack of environmental sustainability associated with growth
Change in underlying theory	Development of linear model (focus of scientific advances as drivers of innovation and consequent socio-economic progress)	Producer-user interactions; innovation systems	Interaction between technological change and socio-technical regimes*
Change in scope	Focus on 'basic' research	Extends into applied research and innovation for economic growth	**Support for breakthrough innovation for transitions (policy imperative 5)** Socio-technical transitions, missions for socio-economic goals
Change in power and governance	Blind delegation of research governance to the scientific community (researcher-governed councils or national science foundations) Generally, in the sphere of education or research ministries	'Science policy' in the OECD sense, with society (industry) increasingly influencing research Generally, in the spheres of education and industry ministries	**Coordinated government (policy imperative 1) and stakeholder engagement (policy imperative 2)** New actors and stakeholders beyond the STI system. It requires a degree of social and political consensus about what the relevant challenges are, how to prioritize them and the direction of the required technical changes and joint action to achieve those changes. Cross-ministry co-operations and all-of-government (incl. ministries in charge often environment, labour, infrastructure, vertical collaboration at local, regional and national levels. Transnational coordination in view of global challenges and requirements for joint action.
Change in organisations, institutions considered	Modern national science foundations, providing external funding (taking over from vertically integrated research councils and academies)	Innovation and 'sector' agencies, companies	**Agility and experimentation in policy and its implementation (Imperative 3) / Stakeholder engagement (Imperative 2)** New formats for government involvement (incl. new support institutions), investment models, wider institutional contributions to reaching policy goals (including companies) involved in implementation
Change in directionality	Towards investigator-initiated basic research	Towards industrial innovation	**Directionality (policy imperative 4)** Towards solving societal challenge-solving innovation and its diffusion.

Note: * Socio-technical regimes refer to the combination of social structures – such as norms, values and practices – and technical systems – such as digital communication tools used available - that shape and influence the behaviour of individuals and organizations within a specific context)
Source: Adapted from Arnold and Barker (Arnold and E. Barker, 2022[7]).

Table 2.2. New policy imperatives for STI policy for transitions

Goal	Policy imperative	Definition
Joint governance	**1: Coordinated government**	A coordinated government integrates and aligns policies across trans-national, national, and sub-national levels of government and different line ministries and agencies.
	2: Stakeholder engagement for joint governance	Actively involving citizens, as well as research institutions, industry and other influential stakeholders in policy processes in order to develop and legitimate shared visions and implement collaborative action plans.
Greater flexibility	**3: Policy agility and experimentation**	Ability to swiftly respond and adapt to changing circumstances in the design and implementation of policies.
Target-setting	**4: Directionality**	Intentional efforts to shape the trajectory and focus of socio-technical change towards specific societal objectives.
Swifter transformations	**5: Support for breakthrough innovation**	Policies aimed at facilitating the development and adoption of disruptive technologies and innovations in support of transitions.

Figure 2.1. Overview of innovation policy imperatives for transitions

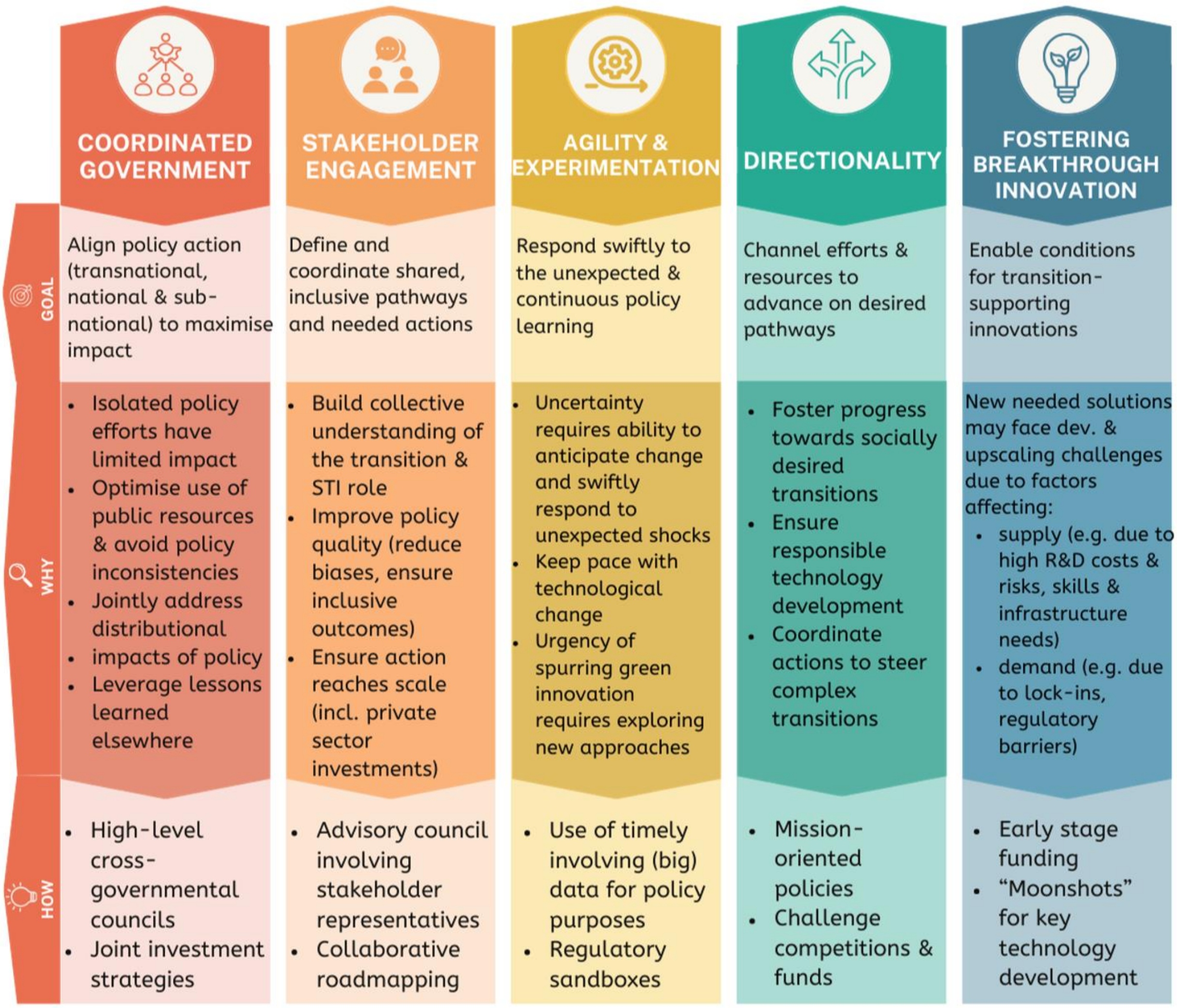
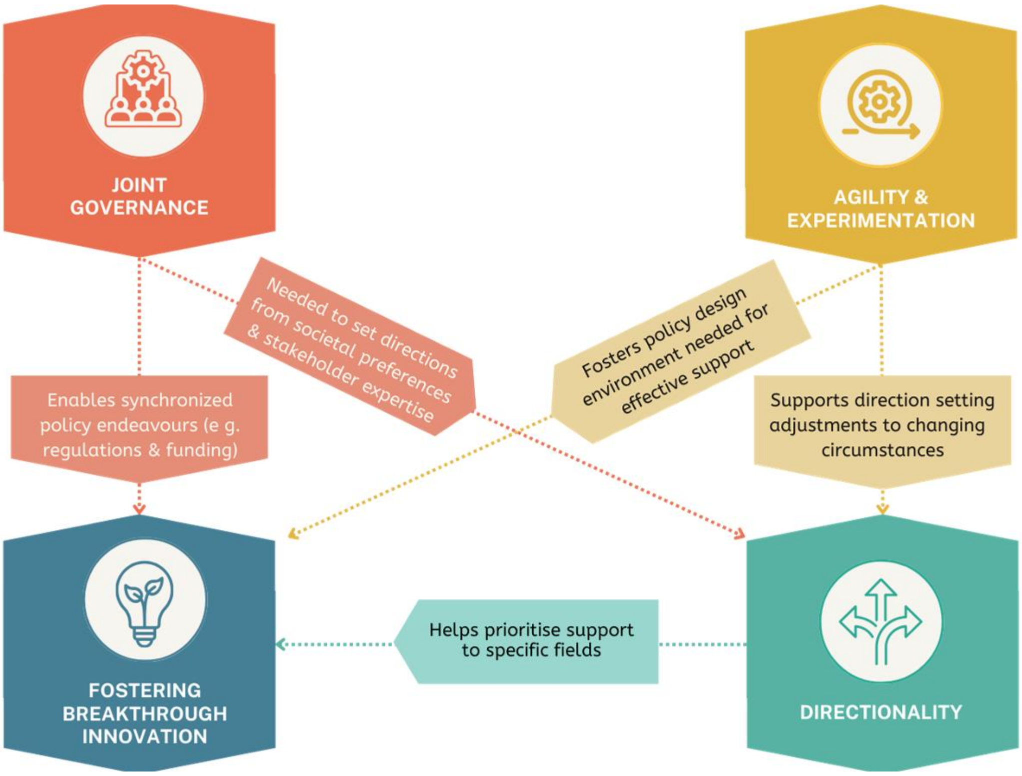


Figure 2.2. Dominant interconnections between innovation policy imperatives



2.2 Need for quality and scaling to mainstream innovation policies

While, as described in sections III to V, countries have addressed the five policy imperatives, the quality of the solutions needs to improve, and their scale expanded as follows:

- **Coordinated government**: Strategies and collaborative institutional design have reduced silos. Yet segmented policy making is still often the norm, specifically when it comes to the execution of policies to reach targets to successfully confront tackling transition challenges.
- **Stakeholder engagement**: Important strides have been made in building engagement platforms with stakeholders and citizens. However, most STI policy is not leveraging those inputs optimally and guiding the actions of industry, research institutions and citizens similarly to the roles of a conductor of an orchestra.
- **Agility and experimentation in STI policy making**: Countries have increased investments to boost the use of timely (big) data and engage more in foresight exercises. Regulatory sandboxes have been widely adopted to experiment in STI policy making. Some efforts have also been undertaken to incentivise a more agile public sector and more experimentation, but more progress is still needed to fully transform STI policy making.
- **Directionality**: Mission-oriented policies of different types have been widely implemented across the OECD with an evaluation of success factors still pending.
- **Fostering breakthrough innovations**: Many countries have increased efforts to support breakthroughs, by providing for risk funding and dedicating "moonshots" to specific technology developments. Yet, the scale of effective support in certain fields is relatively small if green and digital transition goals are to be met.

The seeds planted so far and reviewed in the following 3 sections can help transform STI policies into a flourishing experience and illustrate wide awareness of the importance of those imperatives.

3 Imperatives 1 & 2: Joint governance

3.1 Imperative 1: Coordinated government

The coordinated government imperative

Establishing coordination to effectively implement a given course of government action is necessary for success in the digital and green transitions. This involves both horizontal coordination across different areas of government (e.g. between STI, environment, labour, fiscal and social policies) and vertical coordination across multiple-levels of government, from the local to the regional, national and transnational levels.

Achieving coordinated governance is a challenge due to the siloed government organisation in ministries or departments of state, each responsible for a sector of society (health, education, transport, and so on). The presence of multiple non-aligned layers of government with different priorities and policies at local, regional and national levels challenges governance further. Additionally, communication gaps, political dynamics, and capacity constraints further hinder effective coordination at this level.

The influence of the New Public Management paradigm – which emerged in the 1980s and supports the application of business-like practices in public administration to enhance often short-term narrowly-defined efficiency, effectiveness and accountability – has added more complexities for co-ordination (Natalini and Di Mascio, 2021[8]). One such additional complexity is the devolution of policy to agencies, which has enhanced ministry silos. Another is the addition of more added complexities for managing programmes, leaving fewer capacities for the higher-level cross-governmental cooperation.

Specific dimensions of governance requiring coordination include the following:

- **Horizontal coordination between STI and other policy areas**: Successful policy interventions across different areas of government need to be aligned (Rogge and Reichardt, 2016[9]; Edler et al., 2021[10]). For instance, providing financial support to fossil fuel consumption undermines the economic incentives to invest in renewable energy sources and more sustainable industrial practices. Table 3.1 presents additional examples for which coordination between STI and other policy areas becomes particularly important.
- **Coordination between the national and local levels**: Such coordination is needed to i) implement targeted policies to address different distributional impacts on regions (rather than "one-size-fits-all" national policy measures), and ii) leverage regional experimentation nationally. Regarding (i), collective efforts at local level are needed when "brown" industries are phasing out, to provide for new opportunities and ensure infrastructure developments respond to needs. Meanwhile, national coordination facilitates the integration of regional efforts at larger national scale. As to (ii), local success stories can provide innovative solutions to transition challenges if links to national policymaking are set up (Schwaag-Serger, 2022[11]).

Table 3.1. Coordination between STI and other policy areas: some examples

Policy area	Examples of rationales for coordination
Skills and labour market policies	Equip the workforce with skills to develop and adopt new digital and green technologies, including re-skilling and up-skilling of workers affected by labour market adjustments (e.g. due to automation, decline of certain industries). Attract and retain international highly skilled researchers and qualified workers to advance on transitions research.
Infrastructure (transport and mobility, energy, etc.)	Ensure timely investments in infrastructure needed for the development of new technology solutions (e.g. R&D and demonstration facilities) and their deployment (e.g. network of charging stations for electric vehicles, smart grids, energy storage). Expand the use of public procurement to support the development of innovative transition-promoting solutions (such as innovative green products) across different policy areas (e.g. mobility, energy, housing). This includes pre-commercial procurement (i.e. to develop products, services or processes that do not exist yet) and public procurement of innovative solutions (the public sector acting as an early adopter of innovative solutions which are not yet available on large-scale commercial basis).
Fiscal policies	Encourage business R&D on green technologies (e.g. through grants, awards, favourable tax schemes, low-interest or subsidized loans for young firms, mobilization of government venture capital financing) Carbon pricing schemes to provide revenues to fund support to new green technologies. Redesign of the tax system for its alignment with transition objectives in the longer term, such as e.g. taxing robots to compensate for tax income reductions from less consumption of transport fuels (EEA, 2023[12])

- **Transnational coordination:** Shared and differential opportunities and challenges faced by countries also require international exchanges and coordinated action to achieve the following:
  - share scientific knowledge and coordinate research and innovation efforts to address global public goods challenges (e.g. technologies helping to reduce CO_2 emissions or preserve biodiversity).
  - establish international standards on emerging technologies and business practices to deal with global transition challenges that national governments cannot address in isolation, and ensure transition costs are shared fairly.
  - establish international regulations and standards to facilitate the wider diffusion of innovations across markets (e.g. charging standards for electric vehicles), ensuring minimum quality, safety and environmental standards.
  - share perspectives on desired global futures and identify common approaches to address emerging international transition policy issues, such as the equity, justice and ethical concerns around some technology developments (e.g. generative AI), cybersecurity, and mis- and dis-information.

Country approaches to coordinated government

Horizontal governance

Countries experiment with different governance practices to promote policy coordination in the field of STI, including to promote the green transition. Some countries have a council, committee or "policy arena" – a platform that involves senior politicians and stakeholders in key ministries – or engage in joint programming (Schwaag-Serger, Wise and Arnold, 2015[13]; Borowiecki and Paunov, 2018[14]). Some governments allocate climate change to a single (often super-) ministry (such as the Ministry of Economic Affairs and Climate Policy (EZK) in the Netherlands, or Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) in Austria). Others have created specific structures, such as the UK's Climate Change Committee that answers to Parliament and holds the government accountable for reaching the UK's treaty commitments on decarbonisation, evaluates climate change policy and advises on improvements (Helmer, 2020[15]). Country-specific factors may mediate which of these is best suited to advance on green transition goals in specific countries.

Whatever the institutional arrangement, coordinated governance requires joint policy implementation. In this regard, in presidential democracies, such as the United States, there is a history of appointing senior executive officials to coordinate major priorities and cross-cutting policy issues, often called 'policy czars' (Vaughn and Villalobos, 2015[16]). Specific bodies are also set up, such as the Carbon Cycle Interagency Working Group in the United States, whose members represent 14 federal agencies, regarding the development and execution of the carbon cycle research funded by the US government (CCIWG, 2023[17]). In Norway, Pilot-E is a relatively small funding scheme run jointly by three public agencies aimed at accelerating the development of new solutions in energy and transportation. Inspired by the USA's ARPA-E, it was set up as a one-stop shop where industry-led consortia can access continuous support from applied research to market deployment (Borrás and Schwaag Serger, 2022[18]).

Vertical governance

Regarding enhanced vertical governance, institutional approaches have also been adopted. These mechanisms include, for example, financial incentives to support co-operation between levels of government, co-financing mechanisms, joint investment strategies, the use of conditionalities in the allocation of funds, and dialogue platforms.

Multi-purpose and multi-year contracts between the state and the region for regional development are widely used across countries (OECD, 2018[19]). Climate City Contracts are an example – action and investment plans signed between cities and national governments and co-created with citizens and other city stakeholders to achieve climate neutrality by 2030. Implemented as part of the EU Mission on Climate Neutral Cities, many European cities have signed them including 23 cities in Sweden and 8 in Spain. Additional contracts are in development in other countries including France, Germany and Italy.

There are also many examples of local initiatives that inform national policies in the green transitions space. This is exemplified by the case of renewable energy projects in the Netherlands, during the 2010s decade, where citizen-led cooperatives emerged, driving the development of renewable energy projects, such as wind farms and solar parks. The Dutch government integrated these initiatives into national energy policies and introduced supportive frameworks and regulations to facilitate the expansion of community-led renewable energy projects (Soares da Silva and Horlings, 2019[20]; Halleck Vega and van Twillert, 2023[21]). Another example is the Aspern.mobil LAB, created in 2017 in Seestadt Aspern, Vienna (Austria), which provides collaboration spaces for researchers, citizens, government and private companies to develop sustainable urban mobility solutions with the goal of informing national policy over the longer term (aspern.mobil LAB, 2023[22]) .

Transnational governance

As to trans-national governance, several formats are in place for dialogue on transitions priorities Table 3.2), in addition to multi- and bilateral forums (such as the EU-US Trade and Technology Council) aimed at sharing perspectives on desired global futures. Several have resulted in trans-national agreements, the impact of which on tackling respective green and digital transition challenges has, however, been generally low. Reasons include disagreements across countries on who should bear the costs of tackling climate change, national competitiveness priorities and intensified geopolitical competition. Concepts like "technology sovereignty" and "strategic autonomy" – which refer to a polity's capacity to act strategically and autonomously in an era of intensifying global technology-based competition – could disrupt existing technology ecosystems and international cooperation in science and innovation (OECD, 2023[2]). Finding ways to comfort countries' quest for resilience while promoting collaborations in STI in view of tackling global challenges will be a major imperative for the future.

At the European Union level, the European Green Deal involves a mix of regulations, incentives, investments, and funding mechanisms to promote R&I to tackle climate change, protect the environment and promote sustainable growth. Programmes like Horizon Europe and the Digital Europe support R&I projects, particularly in the areas of green technologies and digital transformation. Furthermore, the European Investment Bank (EIB) provides financing and support for sustainable infrastructure projects.

Table 3.2. Selected transnational governance structures for transitions

Green transition	Digital transition
Fora for global exchange	
United Nations Framework Convention on Climate Change (UNFCCC) and Conference of Parties (COP): Established in 1992, the convention is the parent treaty of the 2015 Paris Agreement, an international treaty aimed at combating climate change by limiting global warming to well below 2 degrees Celsius above pre-industrial levels and striving to keep it below 1.5 degrees Celsius, through the collective efforts of participating countries. The COP is the decision-making body of the UNFCCC that meets every year, gathering representatives of all states that are Parties to the Convention. Innovation has featured in discussions on supporting innovative climate solutions. **United Nations High-level Political Forum on Sustainable Development (HLPF):** Established in 2012, it is the central platform for the follow-up and review of the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs). It meets annually and every 4 years at the level of Heads of State and Government under the auspices of the General Assembly for 2 days. The role of innovation in addressing SDGs has been on the agenda.	**The United Nation's Internet Governance Forum (IGF) and its General Assembly** provide forums for international discussions. The IGF provides a multistakeholder platform under the United Nations for discussions on various aspects of internet governance, including digital technologies, cybersecurity, data protection, access to the internet, and the impact of the digital revolution on societies and economies. The UN's General Assembly has also adopted resolutions on digital policy, internet governance and using the technology for sustainable development. **World Economic Forum (WEF):** The WEF provides a platform for dialogue and collaboration on various aspects of the digital transition, such as digital technologies, the future of work, digital governance, privacy by convening governments, businesses, academia, civil society and international organizations on best practices to shape policies. Most prominent is its annual meeting in Davos, Switzerland, with high-level participation across industry, policy, academia and civil society.
International organisations	
International organizations like the **International Energy Agency (IEA), the United Nations Environment Programme (UNEP)** and the **OECD** (through several committees, working parties and dedicated programmes). Examples of programmes/meetings: • The OECD International Programme for Climate Action (IPAC) and the Inclusive Forum on Carbon Mitigation Approaches facilitate information sharing and policy coordination in climate policy. • The Annual and Spring meetings of the World Bank (WB) and the International Monetary Fund (IMF) have included discussions on the needed investments on climate action in developing countries.	International organizations like the **International Telecommunication Union (ITU)** and the **OECD** (through several committees, working parties and dedicated programmes, including on digital connectivity, broadband access, standardization of ICTs and the socio-economic implications). Examples of programmes: • The OECD/G20 Inclusive Framework on Base Erosion and Profit Shifting (BEPS). Established in 2016, it brings together 138 jurisdictions that agreed in 2023 on a new plan for reforms to address the tax challenges arising from the digitalisation of the economy with regards to multinational enterprises (MNEs) (OECD, 2023[23]).
G7 and G20	
The G7 and G20 Summits serve as platforms for leaders of those countries to exchange and collaborate on a wide range of global policy matters, including climate change and the impacts of digital technologies. Climate change and the digital transformation (incl. digital trade, cybersecurity, social implications of digital technologies) have been a recurring theme in the G7 and G20.	

The case of Germany[2]

The German context exemplifies the challenges involved in achieving coordinated government and at the same time reveals peculiarities. Germany's federal STI policy is driven by the shape of the governing coalition and the pattern of ministries controlled by the individual political parties. Aside from political influences, co-ordination is inherently challenging as ministries compete for budgets, policy priority and attention. Co-ordination at the level of Germany's chancellery may allow for more coordinated action but past attempts to accelerate the digitalisation of the German economy have had limited success.

Table 3.3. Policy approaches for more coordinated government in Germany

What is Germany doing? Some examples	What could be done further?
Horizontal coordination	
Interministerial committees: These coordinating bodies to for initiatives relevant to more than one ministry are usually led by one ministry and regularly bring together representatives of relevant federal ministries. They can take place at various levels of seniority, from policy officers to the level of state secretaries, such as the Committee of State Secretaries on Sustainable Development or State Secretaries' Committee on Hydrogen Cross-ministerial strategies: The Future Research and Innovation Strategy (the main national R&I strategy, which follows from the former High-Tech Strategy) is led by BMBF but involves co-ordination with and funding from all other ministries. To coordination across policy fields, inter-ministerial teams have been created. Other cross-ministerial strategies include the Energy Transition (since 2000), the AI Strategy (2018) and the Action Plan Quantum Technologies (2023)	Further reducing silos within and across ministries by enhancing incentives for cooperation, building on experiences with joint strategies and joint implementation. Consider higher-level co-ordination, incl. as proposed by the EFI, establishing a government committee for innovation and transformation incorporated in the Federal Chancellery (EFI, 2023[25]), subject to legislative framework conditions.
Vertical coordination	
The pact for Research and Innovation, which has run in 5-year periods since 2005, is an agreement between the federal state (BMBF) and the Länder that provides institutional funding increases to the 4 major PROs and the German Research Foundation (DFG) in return for meeting policy targets. The Minister-Presidents' Conference (MPK) are regular meetings between the Federal Chancellor and the heads of government of the Länder to coordinate policy efforts, incl. on the green transition (e.g. expansion of renewable energy). The initiative Intelligent Networks (2014) to advance the digital transformation and its successor *Stadt.Land.Digital* (2018) which focuses on smart cities, bring together actors from all levels of government, with regular coordination meetings between state and federal ministries and local advisory services.	Actively adopt a bottom-up, lead-actor model to help regional authorities adapt their interventions to local realities and needs while contributing to achieve national objectives. Design more spaces for policy exchange and learning across different levels of government to maximize the lessons learned from experiences, allowing to adapt and scale up some of the successful ones at national level.
Transnational coordination	
Major player in the Europe 2020 strategy and the European Semester, which co-ordinates aspects of EU industry policy, and significant roles in the EU Framework Programme for R&I, the European Cooperation in S&T and Eurostars funding programmes, the multilateral European R&D programme Eureka and in facilities-based co-operation, incl. the European Organization for Nuclear Research and the European Molecular Biology Laboratory. Multi- and bilateral co-operation is a central component of its foreign scientific policy. It promoted the establishment of a regular meeting of science and research ministers within the framework of the G7, first held in Germany in 2015. Actively engaged in major multi-lateral discussions outlined in Table 3.3.	Take a more active role in shaping innovation policies at the EU and global level, so that policy caters to the current and future innovation requirements of both Germany and the broader European Union (R10). Engage in efforts to promote standards and quality control procedures at the EU level.

Note: References in the "Would could be done further?" column in brackets, such as R10, refer to the reference of Overall Assessment and Recommendations chapter of (OECD, 2022[1]).

Coordination in the German context is done in various ways across STI policy, which at federal level is mainly located at Federal Ministry of Education and Research (BMBF) and the Ministry for Economic Affairs and Climate Action (BMWK), with the former responsible for research, and the latter for innovation. The Interministerial Committee for Science and Research (Interministerieller Ausschuss für Wissenschaft und Forschung) is a coordinating body led by BMBF in which representatives of the various ministries exchange on research policy overall and the research supported by their respective ministries. Joint management happens only at the top level and across some strategies, with limited evaluation of the latter.

Joint management happens also across strategies. The Future Research and Innovation Strategy ("Zukunftsstrategie") (BMBF, 2023[24]) bundles and coordinates goals, priorities and milestones of the Federal Government's research and innovation policy. Adopted in February 2023, the Strategy develops the mission-oriented approach of its predecessor, the former High-Tech Strategy 2025 to address major societal challenges. Intergovernmental teams participate in the evaluation of the strategy implementation. Moreover, the governance of the strategy involves the independent advisory body Forum #Zukunftsstrategie, which brings together experts from research, industry and civil society to advise the federal government and the teams on the implementation and further development of the strategy.

Germany has implemented several additional actions to strengthen horizontal, vertical and transnational coordination, as illustrated in Table 3.3. This includes the development of other cross-ministerial strategies on key areas, such as the strategies on AI and the Energy Transition; and the organisation of Minister-Presidents' Conferences (MPK), regular meetings between the Federal Chancellor and the heads of government of the Länder to coordinate policy efforts. It has also been active in engaging in trans-national and EU-level discussions and actions.

Going forward, continued efforts at co-ordinating strategies and their implementation and developing a joint future vision further are important to strengthen coordinated government. Institutional novelties, including a cross-ministerial, federal-state-regional, cross-institutional and cross-sectoral forum also contribute to enhancing these transition ambitions (discussed in the concluding section).

3.2 Imperative 2: Stakeholder engagement for joint governance

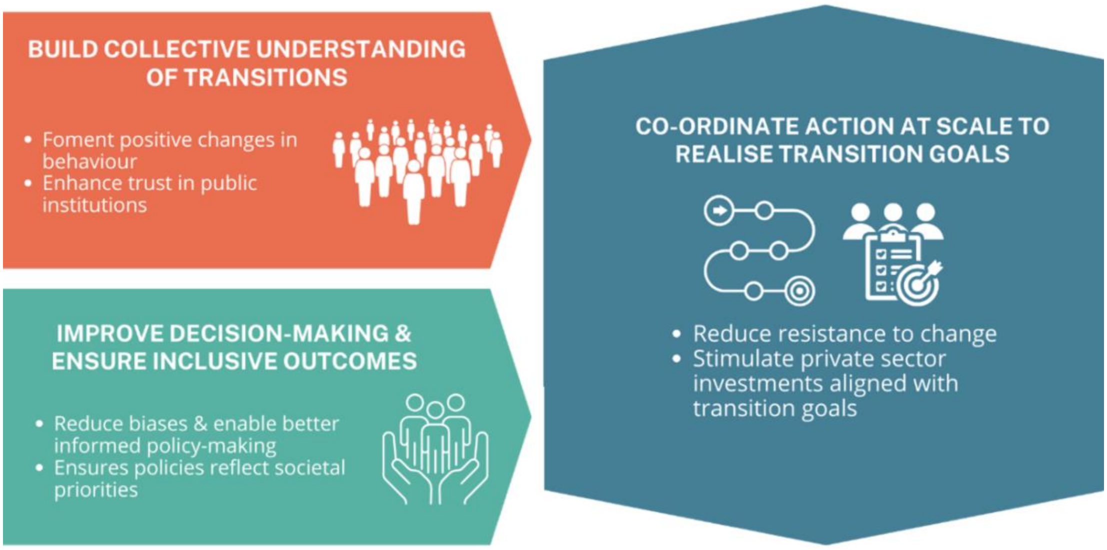
The stakeholder engagement imperative

Stakeholder engagement refers to involving the diversity of actors of the STI ecosystem – citizens, industry and research organisations – in policy making, to integrate their perspectives, concerns, and expertise in the policy-making process. More ambitiously, it refers to the government acting as orchestrator of transition processes undertaken by different actors.

Engagement may involve individuals (incl. representatives across society and experts) and organisations (incl. industry associations, firms, NGOs and research organisations). Included in such endeavours are those with a vested interest in the issues at hand, those affected by a policy issue, and those playing a vital role in moving the STI ecosystem towards the desired transformations.

In the context of the green and digital transitions, stakeholder engagement is essential to i) build a collective understanding of the complexities of transitions and the role of STI and its policies in this context, and enhance trust in government, ii) improve decision-making on directions to take and shape STI system outcomes inclusively and iii) coordinate action at scale to realise transition goals (Figure 3.1).

Figure 3.1. Why is stakeholder engagement important?



I. Stakeholder engagement builds a collective understanding of the complexities of transitions, the role of STI and its policies therein and develops trust in government. Awareness among citizens, firms and research matters to lead to behavioural changes. This includes increased consumer demand for green products, an improved understanding of polluting impacts of economic activities and of possible actions to undertake to contribute to addressing the challenge. By engaging with diverse stakeholder perspectives, addressing concerns, and incorporating those inputs into policy formulation, stakeholder trust in public institutions is enhanced, an essential condition for public sector action in transitions.

II. Inclusive stakeholder engagement also improves policy decision-making and helps develop better and more inclusive STI solutions. Industry and research organizations contribute expertise, innovation, and technical knowledge, enabling more informed policy choices. Citizens' involvement in choices of research funding, for instance, has been shown to lead to decisions that reflected more social priorities than if only experts were involved (Gudowsky and Rosa, 2019[26]). Moreover, creating the conditions for diverse groups to participate in research and innovation efforts for transitions enhances creativity and out-of-the-box thinking to steer transitions in directions relevant to the whole society. Broadening engagement in STI systems tackles the issue of biases (as illustrated by the historical problem of gender bias in medical research) and improving the quality of outcomes.

III. Stakeholder engagement also allows for co-ordinated and inclusive action at scale to realise (STI) transition policy goals. Transitions require private funds to reach scale and substantial behavioural changes across the STI ecosystem, from consumption to production to research activities (Kaufman et al., 2021[27]). Jointly setting the directions for change reduces opposition by considering any concerns and coordinating actions across actors on shared objectives (e.g. different impacts of fuel carbon taxes on rural and urban households). The example of electric mobility illustrates the co-ordination challenge.

Understanding better different incentive structures and adequate modes of engagement is still an area requiring further analysis. With few exceptions, it is only in the past years that the transitions literature has begun to address the role of agency, politics, and government (Ehnert, 2018[28]; Arnold, 2018[29]) and governments' key leadership roles in partnership with research, business and wider society (Wittmayer and Loorbach, 2016[30]). This includes managing interfaces, building platforms and networks, collecting strategic intelligence and articulating demand, visions and strategy. However, attention has focused largely on fragmented lists of largely non-government actors (Kivimaa, 2019[31]; Sovakool et al., 2020[32]) whose incentives for helping are diverse and not always clear. Effective modes of engaging citizens in policymaking are discussed in Paunov and Planes-Satorra (Paunov and Planes-Satorra, 2023[33]).

Country approaches to stakeholder engagement

Stakeholder engagement approaches used across countries include the following:

- *Collaborative road mapping and strategic planning for transitions*: An illustration of this approach is the Automotive Roadmap, which outlines joint government and industry commitments to achieve the decarbonisation of road transport in the UK (GOV.UK, 2022[34]). Another interesting case is the Fossil Free Sweden initiative, established by the Swedish government in 2015. Through this initiative, 22 business sectors have produced roadmaps that chart industry pathways to achieving net zero emissions by 2045 (Fossilfritt Sverige, 2023[35]).
- *Public-private partnerships for innovation ecosystem development*: Several countries, including Finland offer co-funding for "green" R&D projects, including collaborations with other firms (Business Finland, 2023[36]). Public-private partnerships have also been promoted in the Swedish Strategic Innovation Programmes (Åström, Arnold and Olsson, 2021[37]) and in many city-based sustainability interventions. Smart Grid Gotland, launched in 2012 in the island of Gotland in Sweden, is an example of the latter. The project involved Vattenfall, a leading Swedish energy company, and deployed smart meters and monitoring systems to gather real-time data for improved electricity grid management.
- *Multi-stakeholder partnerships, platforms and forums*: Such initiatives bring together multiple stakeholders (government, industry, academia and often civil society actors) to jointly identify priority areas of action and explore innovation-based solutions to address transition challenges. Examples of national and international platforms include the following:
  - *Plattform Industrie 4.0 in Austria:* An association of companies, scientific institutions, employee and employer representatives created in 2015 with the aim of facilitating the digitalisation of manufacturing industry in Austria by facilitating exchange, cooperation and the development of joint strategies,
  - the Technology and Innovation Platforms in Spain: industry-led public-private structures of exchange among research and innovation actors in specific sectors or technology areas, supported by a programme of the Spanish State Agency for Research since 2005 (OECD, 2021).
  - the Global Partnership on AI (GPAI): international and multistakeholder initiative hosted by the OECD to guide the responsible development and use of AI, bringing together AI experts, industry, government and civil society.
- *Stakeholder and public consultations*: Widely used across countries, they can take the form of targeted surveys, stakeholder meetings or online public consultations open to all citizens. An example is the national consultation on digital and data transformation launched by the Government of Canada in 2018, with 30 roundtable discussions organised across Canada with industry, academia and civil society to discuss boosting Canada's position in digital innovation. An example of a survey is the 2017 Deliberative Poll on Nuclear Power Plant Construction in Korea used to learn whether citizens would favour constructing new nuclear plants.
- *Public authorities engaging citizens in policymaking*: Examples are the Climate Assembly UK (2020), which engaged 108 randomly selected citizens to jointly with experts develop policy recommendations to reduce greenhouse gas emissions; the "Attitudes to new transport technologies" project (2021-2022) of the Norwegian Board of Technology, which engaged citizens

to discuss transportation technologies of the future, such as self-driving cars and shared mobility; and the Citizens' Jury on Climate Actions (2021) in Finland, which gathered 33 randomly selected citizens to comment on Finland's policy plans to combat climate change.

Regarding wider participation in STI systems, many countries implement dedicated support programmes for underrepresented groups undertaking R&I activities, such as the Women in CleanTech Challenge in Canada, the Program to Support Research Activities of Female Researchers in Japan and the Competitive Start Fund for Female Entrepreneurs in Ireland. These are often complemented by sectoral and regional initiatives to address related inclusion challenges, such as Israel's Programme for Companies to Establish R&D Centres in the Periphery (Planes-Satorra and Paunov, 2017[38]).

The case of Germany

Several highly successful engagement models in Germany are an asset for transition processes (Table 3.4). This includes established collective bargaining processes between workers and employers that have allowed reaching pragmatic employer-employee agreements. Germany also has much practice with engaging stakeholder representatives across regions, firms and societal groups in policy advisory bodies, including in the STI field. Similarly to many other countries, it faces the challenge of enhancing citizen engagement in STI policy making processes (Paunov and Planes-Satorra, 2023[33]).

There is significant scope for broadening the participation in STI, including notably women, minorities and disadvantaged social groups. Due to the industrial focus of German innovation, the private sector has historically favoured science, technology, engineering and mathematics (STEM) skills, a domain where women continue to be under-represented. More efforts to engage SMEs and address territorial disparities in innovation performance are equally important to meet the innovation needs of the green and digital transitions.

Table 3.4. Policy approaches to stakeholder engagement in Germany

What is Germany doing? Some examples	**What could be done further?**
Involving experts and industry representatives in policy processes	
Tradition of collective bargaining mechanisms between trade unions and employers (e.g. IG Metal) aimed at jointly finding acceptable ways to address crises while defending workers' interests. Councils and advisory bodies including representatives from industry and society: • The Forum #Zukunftsstrategie (formerly the High-Tech Forum), an independent advisory body established in 2023 to advice both the government and the ministerial administration on the implementation of the R&I strategy. • Innovation Dialogue, established in 2009, is a series of high-level discussions between the Federal Government and representatives of science & industry. 6 dialogues took place in 2017-21. • The Council for Technological Sovereignty, created in 2021, includes 11 representatives from science, industry and society to advise BMBF on strengthening the technological sovereignty of Germany and the EU in key technology fields. Platforms and forums: (1) The Plattform Industrie 4.0 gathers business representatives, policy makers and experts from science, associations and trade unions to identify relevant trends in the manufacturing sector and provide policy recommendations. The platform's technical work is carried out in thematic working groups. (2) The "Transformation dialogue for the automotive industry" aims to identify and agree on transition pathways and for government and industry to commit to investments. Engaging stakeholders in programme development: Kopernikus projects are one of Germany's largest research initiatives in the field of energy transition. 90 institutions & organizations were asked what topics of research are key to the success of the energy transition. Answers were used to compile research guidelines and calls for proposals.	Enhance the operations of platforms for joint stakeholder elaborations of transition needs, building on successful bodies and mechanisms. Create a cross-ministerial, federal-state, cross-institutional and cross-sectoral forum (R 1.1) discussed in section 6 also to build cohesion into stakeholder engagement and ensure broad engagement in policy making to secure the social and political legitimacy of the proposed policy actions. Foster regional-federal interactions to leverage learning from regional initiatives nationally.

What is Germany doing? Some examples	**What could be done further?**
Engaging citizens in STI policy and in STI	
Citizens' assemblies: The German Citizens' Assembly on Climate, a foundation-led initiative organised in 2021 by the Bürger Begehren Klimaschutz (BBK), gathered 160 randomly selected citizens to discuss and develop policy recommendations. Other local citizen assemblies have been organized (e.g. in Bonn, Munich and Neumünster) *Participatory strategy setting at local levels:* For instance, during the development of the Innovation Strategy for the City of Hamburg, over 300 representatives from industry, research and higher education, cultural organisations and civil society were consulted to provide input, and jointly identify priorities and objectives (City of Hamburg, 2021[39]). *Citizen science initiatives*: The *Bürger schaffen Wissen* (citizens create knowledge) platform, funded by the Federal Ministry of Education and Research (BMBF), presents, connects and supports Citizen Science projects since 2013. Its main purpose is to increase the visibility of citizen science across society.	Create citizen councils to debate innovation and innovation policy (R 8.1) and provide structured input into STI policy making and direction. Citizen councils' discussions could contribute to developing a guiding vision. Boost diversity in the innovation system (R 8.5). In the context of an ageing society, attracting and involving skilled migrants, women, minorities and individuals from disadvantaged groups in innovation training and careers is critical to ensure the system has the talent it needs to succeed.
Addressing industrial and territorial inclusivity in the STI system	
Initiatives to enhance innovation capacity of SMEs: The Mittelstand 4.0 competence centres act as regional and topic-related contact points for SMEs engaging in digital transformation efforts. They offer neutral, cost-free information, demonstration and accompaniment, incl. visits to demonstration plants, and support for SMEs developing digital solutions. Other initiatives targeting SMEs are "Digital Now – Investment Support for SMEs" and "Zentrales Innovationsprogramm für den Mittelstand" (ZIM). *Cluster initiatives:* BMBF has traditionally funded ambitious, science-based clusters. More recently, it funded the "Leading-Edge Cluster Competition" (2007-17), supporting 15 Clusters of Excellence, and is currently running the "Clusters4Future" competition. Since 2012, BMWK has funded the "Go-Cluster" programme, covering technical services & advice rather than R&D. Regional cluster schemes complement these initiatives. *Regional innovation initiatives:* As part of the "Innovation and Structural Change" initiative, BMBF has run a series of initiatives targeting structurally weak regions to reduce regional disparities. BMBF has supported over 500 regional innovation initiatives since the 1990s. *Initiatives to foster gender equality in R&I*, incl. the Programme for Women Professors of the Federal Government and Länder, the Alliance for Women in STEM Occupations, the Women Enterprise initiative, and support by the National Agency for Women Start-up Activities and Services.	Reduce bureaucratic and administrative barriers affecting SMEs and start-ups. The government should both rationalize the processes required for certain government-to-business services, as well as the administrative steps required for firms to receive STI policy support measures and pursue a programme of digitalising government policy, consolidating interactions of firms, preferably by a digital "one-stop shop".

Note: References in the "Would could be done further?" column in brackets, such as R1.1, refer to the reference of Overall Assessment and Recommendations chapter of (OECD, 2022[1]).

4 Imperative 3: Agility and experimentation in policy making

This section discusses two additional STI policy imperatives: enhancing agility and experimentation in STI policy and fostering breakthrough innovation.

The agility and experimentation imperative

Agility and experimentation in science, technology, and innovation (STI) policy making refer to policy making that embraces flexibility, adaptability and a willingness to try out new ideas and approaches to achieve more effectiveness. This requires strengthening connections between the strategic and policy implementation levels, with the top level overseeing and coordinating STI policy making to attain set goals, the middle level focusing on aligning portfolios of activities with the goals, and the operative level implementing activities aiming for their efficient and effective execution. Clearly defining responsibilities and establishing feedback loops is also essential (Weber et al., 2021[40]).

Agility refers to the ability of STI policy-making processes to prepare for and respond quickly and effectively to changing circumstances, emerging trends, and evolving challenges targeting action at where it is most needed. Agile policymaking is proactive and timely as it anticipates developments requiring action and swiftly executes them. It also requires responsiveness and flexibility, i.e. the ability to react to unexpected developments and needs as they emerge. It also involves the ability to halt policy initiatives that are unsustainable or do not deliver the expected outcomes. Finally, the ability to be as granular as needed in policy interventions (e.g. targeting specific individuals or regions) – as compared to implementing blunt large policy programmes in view of lacking alternative options – is another dimension of agility that contributes to optimising the use of public resources.

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. This includes encouraging out-of-the-box thinking about entirely novel policy programmes. This involves explicit testing of policies paired with risk management that deals with policy failures in a constructive policy learning process. It also involves running policy experiments including randomised control trails or quasi-experiments. Policy learning networks to exchange on policy lessons and adapt policy designs iteratively as evidence on impacts becomes available also plays an important role.

The need for agile and experimental approaches in STI policy has increased due to:

- **The accelerated pace of (digital) technological change**: The rapid advancements in digital technology, illustrated by the widespread adoption of innovations like ChatGPT that reached a massive user base within weeks of its introduction, require policy keeps pace to protect consumers via regulation and industry and research institutions seize innovation opportunities. New “realities” associated to these technologies and their application will require reconsidering the validity of established policy choices.

- **The urgency of spurring green innovation**: Addressing pressing environmental challenges, such as climate change and resource depletion, requires massive progress in innovations. Agile and experimental policy interventions leading to more effective uses of public resources to support these goals are therefore critical.
- **The need for preparedness to operate in a context of uncertainty and vulnerabilities**: The future is marked by uncertainties related to the speed of development and impacts of emerging technologies, complex geopolitical shifts, and the interplay of STI policy with socioeconomic changes caused by technology (e.g. impacts of social media on societal interactions) and other developments (e.g. migratory flows caused by conflicts, phasing out of coal production). The lack of resilience and vulnerabilities in existing systems exposed by the COVID-19 pandemic and the war in Ukraine heighten the need for policy to adapt swiftly and be effective in changing contexts.

Country approaches to agility and experimentation

Table 4.1 and Table 4.2 showcase various examples of how STI policy making can improve its agility and embrace experimentation. Policy agility has been enhanced through efforts to increase policy flexibility, responsiveness and timeliness, the implementation of proactive (instead of reactive) actions to anticipate changing needs and the use of new tools and approaches to provide more targeted policy responses. Experimentation has been promoted through policy and regulatory testing efforts, the implementation of effective policy learning processes and the promotion of a responsible risk-taking culture and out-of-the-box thinking within public administrations.

Table 4.1. Country examples of agile STI policy approaches

Policy making approaches	Policy examples
Flexibility and responsiveness	
Render policy processes quicker by streamlining decision-making processes, minimizing bureaucratic barriers and delays, and ensuring that policy formulation can keep pace. **Changing the mind-set of policy making and public administrations' operations**: Moving away from policy changes being "exceptions" to deal with the digital and green "emergencies" towards a culture that is open to continuous experimentation, learning and adaptation	STI policies' responsiveness was applauded during the COVID-19 crisis, where governments deployed large scale support packages in record times. This included fast-track R&D funding initiatives (e.g. COVID-19 Flash Call in France, Rapid Call for International Joint Research against COVID-19 in Korea) and fast-track open competitions (e.g. COVID-19 Challenge Programme in Canada, COVID-19 Rapid Response Calls in Ireland) (Paunov and Planes-Satorra, 2021[41]). This, however, came at the expense of diverting efforts from other areas, requiring presumably alternative adjustments to deal with the climate emergency. New tools (such as semantic analysis and visualization tools) are used to inform and accelerate policy responses and innovation programmes' deployment. For example: – The innovation agency VINNOVA, together with the Swedish Agency for Growth Policy Analysis, uses a text analysis tool to assess applications for public funding of innovation projects. It allows processing a larger volume of applications without marginal cost increases. – The US National Science Foundation (NSF) developed a visualization tool that clusters all NSF-funded research projects related to COVID-19 into groups of similar topics, based on the application of machine-learning techniques to abstracts of project proposals. The objective was to reduce the risks of duplicating grant awards, identify synergies across projects, and map the relative importance of research areas being funded (Columbia University, 2020[42]).
Timeliness	
"Now-casting" developments in the STI ecosystem by gathering and exploiting efficiently timely (big) data (incl. satellite data) and text data using machine learning and natural language processing tools, to provide real-time insights to inform policy decisions.	Machine learning and semantic analysis techniques are being used across policy domains to exploit different types of **granular and (near) real-time data** such as: – Satellite imagery data to monitor land use and change, terrestrial and marine protected areas, and to detect illegal logging (OECD, 2023[43]). – Online job postings data to monitor changing demands for skills (e.g. AI skills) in the labour markets and across geographies (Manca, 2023[44]).

Policy making approaches	Policy examples
Develop early warning systems to detect where policy action is needed.	– Data on international shipping tracked for security to infer freight transportation, trade flows and the evolution of Co2 emissions in real time (IMO, 2020[45]) from the AIS data provided by UN Committee of Experts on Big Data and Data Science **Pulse surveys** (brief online questionnaires sent regularly to targeted respondents) are used to gather timely data. Launched in April 2020, the Small Business Pulse Survey of the US Census Bureau collected weekly data generating near-real-time snapshots of the impact of COVID-19 on SMEs.
Proactive actions	
Using anticipatory and forward-looking approaches– e.g. by use of strategic foresight which is a structured way of exploring ideas about the future, as well as technology assessment, an evidence-based, interactive process to identify the consequences of emerging technologies (Robinson, Winickoff and Kreiling, 2023[46]).	**Strategic foresight** has been institutionalized in government (and STI policy in particular) in several countries. In Australia, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (the national science agency) has a dedicated foresight team (CSIRO Futures) and an Insight Team that analyses emerging trends, drivers and scenarios, and applies modelling approaches to generate insights and inform future strategy and policy decisions with a particular focus on digital technology and data driven science. Other examples include the Policy Horizons Canada, Finland's National Foresight Network, and the Estonian Foresight Centre. **Technology assessment** to gather strategic intelligence on emerging technologies. For instance, the Expert and Citizen Assessment of Science and Technology (ECAST) network, a distributed network of institutions led by the Arizona State University, the Museum of Science of Boston and SciStarter, has conducted several large-scale public deliberations involving universities, research institutions and think tanks in the United States, on issues also related to transition questions such as driverless car technologies and climate change (ECAST, 2022[47]).
Targeted policy responses	
Monitoring developments at granular level: Gathering and exploitation of big data and AI-empowered tools on micro-statistical data sources (incl. satellite data and tracking schemes). **Embracing bottom-up approaches** to policy making, encouraging actors at local levels or sectors to propose context-specific solutions. **Integrating a focus on differential impacts** – rather than simply average effects – of policy programmes and build in options for fine-tuning in response to those effects.	Impact Canada, a Canadian government initiative, has conducted **surveys to profile different social groups** with regards to their attitudes towards climate change, enabling to engage different segments of society in policymaking in a more tailored way (Impact Canada, 2023[48]). The European Environmental Agency (EEA) provides a granular index on air quality that is calculated hourly for more than 3.500 air quality monitoring stations across Europe. This allows tracking high pollution concentration at granular regional level (EEA, 2023[49]). The use of low-cost sensors has been used across several European cities - incl. Athens and Helsinki - to track air pollution in more detail to inform health policies in specific locations (European Commission, 2022[50]).

Table 4.2. Country examples of experimentation in STI policy

Policy making approaches	Policy examples
Policy testing	
Conduct randomised control trials (RCTs) to assess proposed policy approaches. **Implement policies at small scale** before expanding policies, including exploiting experimentation at local levels.	NESTA's Innovation Growth Lab (IGL) and the EU's Joint Research Centre's Policy Lab have run several randomised controlled trials (RCTs), including testing of innovation support programmes for SMEs (European Commission, 2022[50]). In Canada, Experimentation Works encourages public servants to incorporate experimentation into their work by providing on-the-job coaching.
Regulatory testing	
Enable more flexible regulations and adapting regulatory enforcement activities to evolving needs, in line with the OECD Recommendation of the Council for Agile Regulatory Governance to Harness Innovation (OECD, 2021[51]).	Exceptional regulatory flexibilities were implemented during the pandemic to accelerate the approval processes for new products that tackled COVID-19 while maintaining the necessary safeguards. These often drew from existing emergency procedures of regulatory bodies.

Policy making approaches	Policy examples
Regulatory sandboxes and experimental clauses to test new regulations.	Spain launched an AI regulatory sandbox in 2022 as the first pilot program to test the future EU regulatory framework for AI: the EU AI Act (expected for 2025) (OECD, 2023[52]). The Council of the European Union adopted its premier conclusions on regulatory sandboxes and experimentation clauses during the 2020 German EU Council Presidency, recognizing these as instruments to create an innovation-friendly and futureproof legal framework.
Risk management (also related to imperative 5 on breakthrough innovations)	
Adopt a portfolio approach to STI policy making: Finding optimal approach to dealing with failure, considering that the responsible management of public budgets and public officials' accountability to the public for their decisions need to be preserved. This would involve risk taking across projects within an umbrella programme that is evaluated for its overall impacts rather than wins across specific programmes, incl. by setting up interrelated projects that complement and feed into each other, considering some may not succeed from the programmes' inception. **Create institutional structure or programmes prone to risk-taking**, included dedicated budget for pilot programmes with "eased" regulatory provisions at lower-scale or, alternatively.	A range of 'moonshot' challenge-oriented programmes have been implemented across countries, inspired by the DARPA model. Such initiatives provide funding to a portfolio of projects that use diverse approaches to address specific goals. Examples include the Pilot-E initiative in Norway and the Industrial Strategy Fund in the United Kingdom. An initiative financed by foundations, companies, individuals and public institutions is the Joint European Disruptive Initiative (JEDI). In 2016, the Treasury Board Secretariat and Privy Council Office to the President of the Treasury Board of Canada issued a directive on experimentation for more effective policy making and called for government departments to allocate part of their programme funding to experimentation. Impact Canada was established in 2017 to support departments in their experimentation with prizes, challenges, micro-funding and other outcomes based and innovative funding approaches.
Policy learning	
Institutional cultures that encourage the sharing and experimentation with new ideas, moving away from fixed roadmaps and strategies to be able to adjust them where needed. **Create mechanisms whereby policy experiences are discussed with those engaging in similar efforts** (e.g. cross-country exchanges on policy initiatives), between those administering policies and the targets, with experts and citizens for critical feedback on policy results.	**Policy laboratories** have gained increasing attention as a way of experimenting with new policy approaches and tools. Examples include the EU Policy Lab, the UK Government Policy Lab, the RISE Policy Lab in Sweden, the Laboratorio de Gobierno in Chile, the GovLabAustria, and the Public Innovation Laboratories in France. For example, the EU Policy Lab is implementing a participatory design and behavioural science approach to develop harmonized waste sorting labels for all EU countries (European Commission, 2023[53]). Trans-national forums for best-practice exchanges on STI policymaking, incl. the OECD and other international organizations, and university- or government-led efforts (e.g. Transformative Innovation Policy Consortium (TIPC), UCL Institute for Innovation and Public Purpose, Mission-Oriented Innovation Policy Observatory at Utrecht University, G7, G20, etc.)
Out-of-the-box thinking	
Institutional structures to allow for experimentation by rewarding champions in the public sector engaged in entrepreneurial policy efforts & senior management support of bottom-up initiatives aimed at renewal of institutional cultures and mindsets. **Engaging in horizon scanning of alternative policy approaches** (e.g. implemented at local, regional or international level, in other policy fields) and willingness to question existing practices.	Public Sector Innovation Awards in Australia (2016-2020) aimed at recognizing, celebrating and sharing innovation in the Australian Public Service. They were held by the Institute of Public Administration Australia, Department of Industry, Innovation and Science and the Public Sector Innovation Network (PSIN). Awards were given across three categories: citizen-centered innovation; culture and capability; digital and data. The "Place to Experiment" initiative from Finland, created in 2015, is a digital platform that supports an experimental culture to find innovative ways to develop public services. This aims at encouraging a shift from a top-down development of public services to a more co-created – in some cases even crowdsourced or crowdfunded – process for public sector innovation (OECD, 2017[54]).

The case of Germany

Germany has a sophisticated STI policy system at both federal and state levels with an impressive well-funded set of policy instruments deployed across all core areas of policy making. Efforts are in place to make policymaking more agile and promote regulatory experimentation, notably through the implementation of regulatory sandboxes (Table 4.3). However, the German public sector makes limited use of new and digital tools and approaches to deal with disruptive change and transitions and improve STI policy, including through public consultation, policy experimentation, and advanced data-analytics tools exploiting large data from the STI system. A key message in the *OECD Review of Innovation Policy: Germany* is the need to support and mainstream greater agility – taken here to mean a combination of speed, flexibility and experimentation – in German policymaking and governance, both in STI and beyond.

Table 4.3. Agility and experimentation in STI policy in Germany

What is Germany doing? Some examples	**What could be done further?**
Making public administration more agile	
Dedicated mobility programmes ("Work4Germany" and "Tech4Germany") for temporarily employing private-sector professionals in the public sector. "Federal Cloud" for intra-governmental online services & law on the harmonisation of registers in Germany (*Registermodernisierungsgesetz, 2021*) to facilitate digital data exchanges between different government departments. Reform advice from advisory bodies, such as the Commission of Experts for Research and Innovation (EFI) and state-owned consulting companies (e.g. *PD – Berater der öffentlichen Hand)*.	Identifying examples of agility within German STI and explore mechanisms that could be used to scale the most impactful of these examples, including at state and local levels. Reduce bureaucratic and administrative barriers affecting SMEs and start-ups (R 3). Pursue a programme of digitalising government policy, services and processes (R 3). Increase the public sectors' digital absorption capacities and infrastructure (R4).
Enhancing policy and regulatory experimentation (related to imperative 5 on fostering breakthrough innovations)	
Labs to promote (digital) leadership in the administration, such as the "Reallabor Agiles Arbeiten" and its predecessor project "AgilKom" that provide for an exchange platform and coaching on agile management. BMWK has been implementing a cross-governmental sandbox strategy and issued a *Handbook for Regulatory Sandboxes* in 2018. The first experimentation clauses were introduced in German Law in the 1950s, and have expanded rapidly with the digital transformation. In 2020, the BMWi issued a guide for formulating experimental clauses.	Establish a public-private policy laboratory to support champions, including public bodies undertaking regulatory experimentation and innovation public procurement, as well as city initiatives and other bottom-up efforts supporting transitions (R 2). Expand the use of regulatory sandboxes, by i) strengthening regulatory co-operation across federal regulators and among local, state and federal authorities when implementing sandboxes; ii) targeting SMEs and start-ups to ensure they have access to regulatory sandboxes and that the eligibility criteria do not exclude younger or smaller firms (R 3). Leverage the federal-state structure for state experimentation to inform federal policy more.

Note: References in the "Would could be done further?" column in brackets, such as R3, refer to the reference of Overall Assessment and Recommendations chapter of (OECD, 2022[1]).

5 Imperatives 4 and 5: Directionality and fostering breakthrough innovation

5.1 Imperative 4. The directionality imperative

The directionality imperative and its challenges

Directionality is the government pursuing challenge-based STI policy making, aiming to link wicked societal problems (needs) to the supply of solutions. Directionality is imperative in transitions for the following reasons:

- **Fostering the desired societal transition**: Progress may not be forthcoming or be in the direction desired to achieve societal goals, e.g. advances in green technology to allow for carbon-neutral production, due to market and coordination failures.
- **Ensuring responsible digital technology development**: The speed of developments in digital technologies has led to calls for caution from industry, including a request from US technology leaders and researchers urging AI labs to pause development given "profound risks to society and humanity" (Future of Life Institute, 2023[55]). Directing responsible technology development and deployment and building technological sovereignty reflect an increasing demand for more directionality as compared to leaving decisions entirely to markets.
- **Coordinating complex transitions**: The government is in a unique position to ensure coordinated actions as it is responsible for regulation, setting market conditions and building infrastructure aside from providing funding. This is exemplified by what is needed to deploy wind energy, which requires regulations and standards for permitting the deployment and grid integration of wind farms. Moreover, financial incentives, such as tax credits or feed-in tariffs, affect private investment in wind energy projects.

Directionality contrasts with Washington-consensus-type policies supported by mainstream economics that emphasised that the role of government should be restricted to providing for market conditions, leaving all directional decisions to industry. There policies were also in vogue much beyond developing countries. Past industrial policies had resulted in massive government spending with many failures caused by the market distortions (protectionism) that were introduced. However, there were also important successes, such as Japan's investments in microelectronics, and Chinese Taiwan's investments in semiconductors. New approaches to identifying the impacts of industrial policies also provide a more positive verdict on their impacts (Rodrik et al., 2023).

Directionality can co-exist with principles of leaving choices of technologies to markets and of research foci on researchers but with some limitations. Setting goals to reach can provide for diverse avenues to reach them. There are, however, certain limitations to reconciling both when it comes to policy making, for instance, by choices being made on the types of research fields engaged in green growth strategies or green energy choices as these require suitable infrastructure to be installed and then stimulate innovation. Current policy agendas on technology sovereignty, involving technology areas ranging from artificial intelligence to semiconductors, batteries and biotechnology, are accompanied by more interventionist policy actions akin to past industrial policy principles, focused however on wider technology areas.

The directionality imperative is supported by the recognition that both technical and social factors affect technological change. Dosi (1982[56]) suggests that there are technological paradigms –analogous to scientific paradigms (Kuhn, 1970[57])– that shape the way technologies are developed and articulated, resulting in technology-specific development trajectories. Evolutionary economists have produced the idea of technological regimes (Nelson, 1982[58]), spanning not only the internal logic of the way technology develops but also the context, including rules, norms, skills, and infrastructure, within which it does so. Theories of social construction of technology within S&T studies address ways in which social relations are manifested in the design of technologies (Bijker, Hughes and Pinch, 1987[59]). Feminist analyses point to the design of technologies that reflect and strengthen the power imbalance between genders (Faulkner and Arnold, 1985[60]). The Marxist 'labour process' tradition emphasises the role of technological developments that de-skill work and disempower workers under industrial capitalism (Braverman, 1974[61]). Recent work in economics on the future of work argues that institutional and legal path dependencies, such as in taxation, can favour investments in technologies at the expense of labour and human capital (Acemoglu, Manera and Restrepo, 2020[62]).

Trans-national and country approaches to directionality

The most important trend to implement directionality in recent years has been the implementation of mission-oriented policies (MOIPs) across EU countries. MOIPs are a co-ordinated package of policy and regulatory measures tailored specifically to mobilise STI to address well-defined objectives related to a societal challenge, in a defined timeframe. MOIPs take a variety of organisational forms, such as for instance a strategic or policy framework, a programme or a policy scheme (Larrue, 2021[63]).

Following the proposal by Mazzucato (2018[64]), missions should aim at addressing a delimited, time-bound set of goals contributing to much larger societal challenges. This reduces the scale of the challenge to something that the EU (and eventually also individual Member States) could contemplate funding.

The European Commission formally incorporated societal challenges into the structure of the eighth EU Framework Programme (2014-2020) – Horizon 2020– and funded a range of STI projects that could contribute to their resolution. The Commission subsequently built five missions into the fabric of the ninth EU Framework Programme (2021-2027, Horizon Europe) that strongly feature dimensions of the green dimensions: adapting to climate change, protecting the ocean, seas and waters, living in greener cities and ensuring healthy soil and food. The fifth theme is fighting cancer.

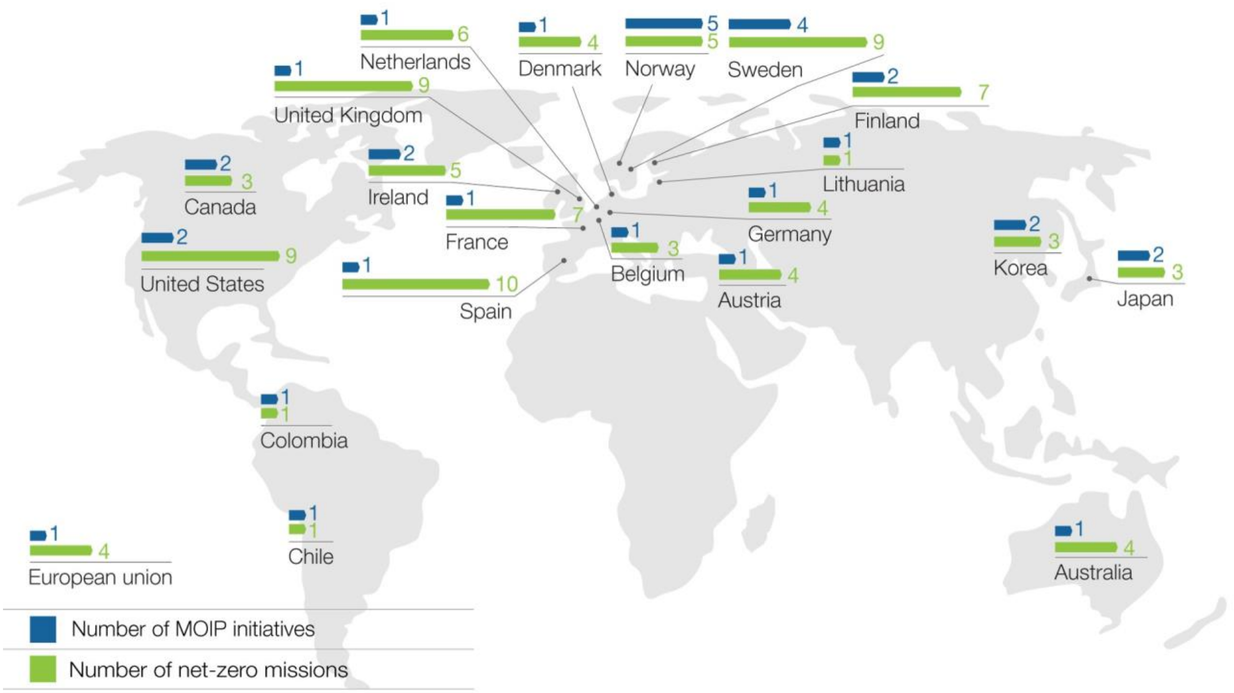
An OECD report gathered 83 net-zero missions implemented in 20 countries in 2022 as part of 30 MOIP initiatives (Figure 5.1) (OECD, 2023[2]). This includes mission-oriented strategic frameworks, such as the mission-driven top sector and innovation policy in the Netherlands; challenge-based programmes such as Pilot-E in Norway and the Industrial Strategy Challenge Fund in the UK; and thematic mission-oriented programmes, such as Mobility of the Future and Building of Tomorrow in Austria (Larrue, 2021[63]).

Regarding the nature of issues to be addressed, green transition objectives play a major role in STI policy making. A recent empirical analysis using natural language processing tools examined STI strategies from 24 OECD countries in place in the 2021 period. The findings reveal that innovation policy 3.0 objectives take precedence in these strategies (53.5% versus 23.8%), holding twice the significance of traditional innovation policy themes related to business and research innovation performance (Einhoff and Paunov, Forthcoming[3]). Approximately half of the innovation policy 3.0 objectives are aligned with green transition goals, with a primary focus on alternative energy generation and the reduction of CO_2 emissions (7.5%). Additionally, clean mobility and sustainable industries (6.2%) are specific targets within these policies. However, other aspects of green transitions, such as biodiversity, circular economy, climate resilience, and water conservation, receive comparatively less attention. This disparity may arise from perceived differences in prioritization and the perceived contribution of STI to these goals in broader climate change discussions.

Several shortcomings of missions may affect their success. Looking for problems to fit into the "missions" box should not hamper governments in setting overall priorities. The most important challenge, however, is that missions do not address shortcomings related to lack of co-ordinated government actions (with governments still working mostly in silos) and resource attributions may not always best respond to the needs of mission (which often consist in the repackaging of existing funding arrangements). As a result, governments fail to work flexibly with existing resources or adjust programmes where needed in agile ways. Missions also ignore or neglect how to handle resistance to changes that might be necessary for missions to succeed.

Figure 5.1. Map of mission-oriented innovation policies and their net-zero missions

An increasing number of countries have engaged in systemic policies to reduce GHG emissions



Note: For instance, Ireland currently operates two MOIP initiatives which include a total of 4 missions. The list of MOIP initiatives, as well as their net-zero missions, is available at: www.oecd.org/sti/inno/Online%20list%20of%20NZ%20missions.pdf.
Source: (OECD, 2023[2]).

Furthermore, a major challenge for missions to advance is to avoid them being a pure exercise of relabelling, as illustrated by the proliferation of policy actions targeting the United Nations' Sustainable Development Goals (SDGs). While agreeing on the SDGs was a major achievement by the United Nations and its members, an undesirable side effect has been the encouragement of governments to rebrand old activities as new interventions. The 17 SDG goals and 169 sub-goals are so wide-ranging that they relate to almost any well-intentioned policy, but provide no basis for prioritising among them, and fail to recognise frictions among the goals (Lundin and Schwaag-Serger, 2018[65]).

The United States has a long tradition of ‘challenge’ funding, an important type of ‘directional’ STI policy. The archetype was President Kennedy’s ‘Moon shot’ Apollo programme, aiming to land a man on the Moon and return him safely to Earth before the end of the 1960s. In more recent years, the US Defense Advanced Research Projects Agency (DARPA) and other government agencies, as well as non-governmental non-profits like the National Academy of Engineering and the Gates Foundation, have run ‘grand challenge’ competitions (Hicks, 2016[66]). Narrower in ambition compared to the EU’s missions described above, these challenges can be addressed by producing technical solutions that can be slotted into existing systems. By contrast, solving societal (or, more precisely, socio-technical) challenges as exemplified by the EU’s missions requires not only changes in technology but also changes in societal and human behaviour. The UK Research and Innovation (UKRI) Challenge Fund and the National Challenge Fund in Ireland are examples of European approaches in that direction.

The case of Germany

Directionality requires adjustments to the principles of ‘technology neutrality’ in innovation policy and academic freedom in science policy which have underpinned Germany’s STI policy making for decades. The concept of directionality challenges the principle of technology neutrality implicit in *Ordnungspolitik* which are governance principles in favour of economic competition and freedom for economic activity. The adoption of R&D tax credits in 2019 strengthened the weight of technology-neutral innovation policy tools within the envelope of innovation policies. This “neutral” position, however, is not in all dimensions at odds with directionality, since directions set – such as reducing CO2 emissions or increasing the share of renewable energy – can allow for markets and researchers to freely decide on their efforts.

Within its prevailing neutrality approach, Germany has integrated interventions that focus on key technologies or sectors. Examples include supporting dissemination and industrial capacity-building in specific technologies, starting with support for microelectronics and computer-aided manufacturing since the 1980s. Examples of today’s key technology support include the following:

- The *Industriestrategie* (industrial strategy) of 2023 emphasises the need to support key transformative industries for resilience and the climate transition (BMWK, 2023[67]); its predecessor (BMWi, 2019[68]) already included a list of key innovative industries to be safeguarded for competitiveness, based on the principle of European technological sovereignty.
- Strategies for climate protection including support for specific technologies, such as hydrogen and batteries (BMWi, 2020[69]).
- Applied R&D activities provided by the BMWK to help commercialise research, for example on industrial biotechnology and lightweight construction.
- Key interventions by BMBF, such as the “Research Programme Quantum Systems” (BMBF, 2022[70]) and its predecessors, including the framework programme “Quantum technologies – from basic research to market” (2018), or BMBF’s AI Action Plan (BMBF, 2023[71]) are further examples of technology-focused policy making on the side of research.

The best example of mission-oriented STI policy in Germany is the strategy for R&I. The Future Research and Innovation Strategy launched in February 2023, which follows from the former High-Tech Strategy that was first launched in 2006 and revised in 2010, 2014 and 2018. The former High-Tech Strategy transitioned from technology-focused innovation goals related to 17 specific technologies (in 2006), to 6 “grand challenges” (in 2010). It then adopted a “mission-based” approach in 2014. The 2018 revision identified 12 missions across the broad areas of technology and mobility, sustainability and environment, and health and change. The current Future Research and Innovation Strategy (BMBF, 2023[24]) builds on six missions (Figure 5.2).

Improvements Germany can introduce to enhance its mission-oriented policies' contributions to transitions includes the following:

- Foster transformative missions: Some of the missions of the Future Research and Innovation Strategy have the potential to further develop their transformative character further. This should ideally be combined with an appropriate support for continuity.
- Continue to build missions' links to other policy domains: The six missions of the Future Research and Innovation Strategy operate through cross-ministerial co-ordination at the cabinet level and at the level of ministerial administration. This approach should be evaluated and be further developed in the future to guarantee whole-of-government missions.
- Making better use of universities and institutes: Utilising the research system to realise mission goals could enhance their chances of success but adequate policy options need to be identified in view of the high institutional autonomy of Germany's research institutions.

Figure 5.2. Six missions of the Future Research and Innovation Strategy

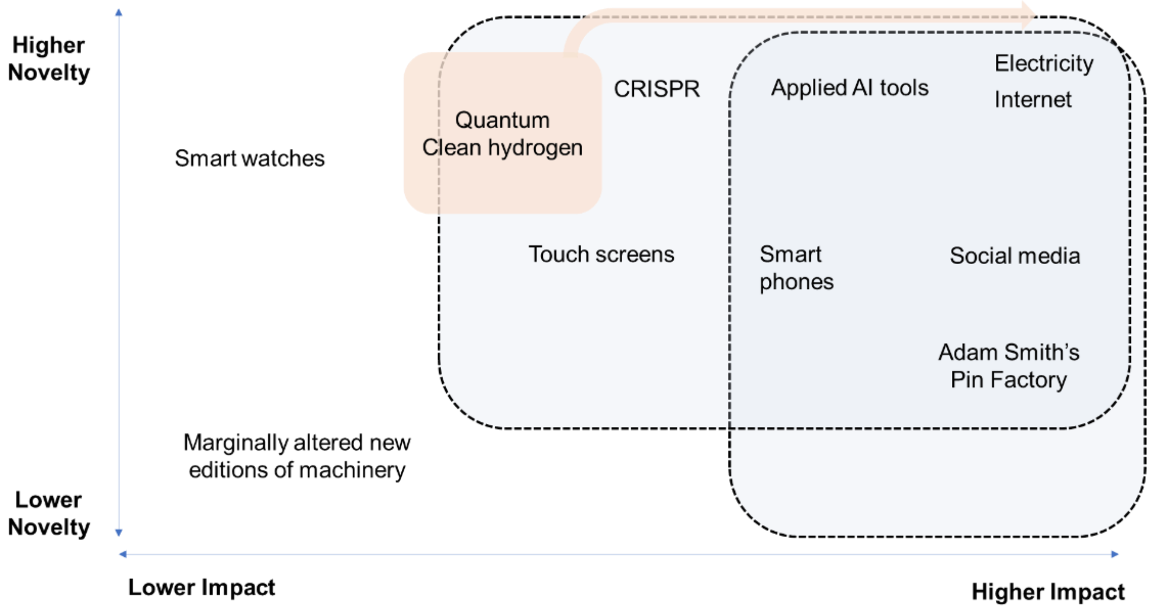
Source: (BMBF, 2023[24]).

5.2 Imperative 5: Fostering breakthrough innovation to achieve transitions

The imperative for breakthrough innovation

Breakthrough innovations – also referred to in the literature as radical innovations, discontinuous innovation, disruptive innovations, or major innovations (Sandberg and Aarikka-Stenroos, 2014[72]) – differ from other innovations by having i) higher realised or potential future societal impact and ii) higher scientific novelty than other (incremental) innovations (Figure 5.3) Examples of breakthrough innovation include "the telegraph, the elevator, the typewriter, the telephone, electric light, the airplane, frozen foods, television, plastics, computers and advances in modern genetics" (Kelly et al., 2021[73]). General purpose technologies (GPTs) exemplified by electricity and the Internet are highest on the impact scales since, by definition, they have a wide scale of application. As illustrated in Figure 5.3, the exact boundaries of where breakthrough innovations ends across both axes is not clear-cut but gradual.

Figure 5.3. Illustrative sketch of the universe(s) of breakthrough innovations



The emphasis set on breakthrough innovation should not be misconstrued as an argument against incremental innovation, which is equally crucial for driving progress in the realms of green and digital transformations. Nevertheless, it is essential to acknowledge that the existing innovation ecosystem is typically more accommodating and readily supportive of incremental innovations compared to their breakthrough counterparts, considering the dimensions outlined.

The policy relevance of breakthrough innovations stems from their potential to respond to societal goals and support competitiveness and societal objectives. The development of advanced carbon capture technologies and sustainable transportation systems exemplifies why breakthrough innovation is essential for the green transition to achieve significant emissions reduction and environmental preservation. The International Energy Agency (IEA) estimates that most clean-energy technologies, such as green hydrogen, would need to reach markets by 2030 at the latest to achieve the goal of net-zero emissions in the energy sector by 2050. This pace is much faster than what has been achieved historically. Breakthroughs matter also for advancing on other societal goals, as well illustrated in the field of health, ranging from addressing cancer and genetic disorders to preparing for future pandemics (IEA, 2023[74]).

Past years have also shown significant market disruption in the digital transition, affecting traditional sectors as diverse as automotive, retail and agriculture (Paunov & Planes-Satorra, 2019). The opportunity and threat of similar industry-level market developments to that of the smart phone replacing the mobile phone have consequently resulted in interest in breakthroughs. Participating in constructing AI applications of the future that reflect societal values is another reason for country interest in leading on breakthroughs.

There are two dimensions of policy support towards those innovations. One relates to supporting the supply side – the production of breakthrough innovations, including by supporting research – and the other relates to the demand side – the deployment and diffusion of those breakthroughs (Table 5.1).

Table 5.1. Factors affecting supply and demand-side support for breakthrough innovation

Supply side support	Demand side support
Research, development and scaling costs: The development of disruptive technologies often builds on long-term and sustained investments in research. Market deployment of disruptive inventions can also be expensive. For example, in the case of electric vehicles, massive investments in R&D have been necessary to advance battery technology, improve energy storage capacity, build up suitable manufacturing capabilities, and progressively deploy networks of charging stations.	**Lack of demand**: One of the challenges faced by breakthrough innovations is that there may be a lack of (sufficient) immediate demand. This can be due to a range of factors, including high cost at the time of initial market entry, lack of sufficient investments in enabling infrastructures and lack of awareness by consumers about the benefits and features of the new technology.
Risks and uncertainties in the development process: Financing breakthrough innovation involves higher risk – at least in the early stages, even though the payoffs may be greater if the innovation reaches scale. Policy and regulatory uncertainty can delay investments in R&D or postpone innovation projects (Kyaw, 2022[75]). Start-up support gains in importance in this context, since they are more likely than incumbents or large firms to embrace radically new products, solutions and business models.	**Risks and uncertainties in the deployment process:** Scaling breakthroughs may be riskier because it is unknown how markets will react to them. Smart phones succeeded while multi-functional digital wristbands have had a much slower success rate to date.
Science-industry linkages, multi-disciplinarity and multi-spectrality: Breakthroughs often result from combining different fields of researchers (novelty generation potential) and also from the application of existing technologies to new areas, as illustrated by the use of drones originally developed in warfare for crop management in agriculture. In many cases, they also originate from joint efforts between business and public research.	**Substantial switching costs due to lock-ins:** Lock-in refers to the situation where actors become dependent on existing technologies, processes, or markets, making it difficult for them to switch to a radically different alternative. Even if a new solution promises significant benefits, the costs associated with transitioning and reorganizing existing systems may be too high for individual stakeholders. Coordination among multiple stakeholders is necessary to collectively shift to the new paradigm.
Research and testing infrastructures: The development of breakthrough innovations often builds on researchers and innovators having access to leading-edge scientific and technical infrastructures (e.g. supercomputers, biomedical imaging, fusion laboratories, oceanographic research vessels). For example, the test side of the Oceanic Platform of the Canary Islands (PLOCAN) or the Biscay Marine Energy Platform (BiMEP) in Spain allow technology developers in the field of renewable marine energy to install and test their new equipment (Ministry of Science and Innovation, 2023[76]).	**Disruptive societal impacts due to highly transformative changes**: Breakthrough innovations can trigger disruptive changes in industries, markets, and society. While these changes may bring about positive outcomes in the longer term, in some cases they also have distributional impacts ("winners" and "losers") and therefore face significant resistance from parts of society.
Skills needs: A wide range of competences that go beyond R&D and technical skills are needed. These include capacities to recognize, create and articulate breakthrough innovation opportunities; to pursue activities that convert R&D findings into marketable innovations; and to accelerate and scale such innovations.	**Regulatory conditions**: Certain breakthroughs may face regulatory hurdles or require changes in existing regulations before they can be widely adopted. Such barriers can delay or limit market entry.

Country approaches to supporting breakthrough innovation

Table 5.2 and Table 5.3 showcase various examples of how STI policy making can support breakthrough innovation. These include actions to tackle the supply and demand side factors discussed above.

The difficulty for policymakers in designing and implementing policy for breakthrough innovation is significant. There will be coordination and framework questions – such as ensuring the infrastructure is in place to allow breakthroughs to be scaled and become systemic, supporting the development of skills in new areas for industry, providing the finance necessary for riskier innovations to get off the ground – that may limit the real-world *impact* of the breakthrough in question. Great ideas once developed may provide little return to taxpayers if they are ultimately scaled elsewhere. Moreover, many of the factors driving incentives for breakthrough innovation, and that may support firms in undertaking R&D to those ends, are beyond the boundaries of traditional STI policy: fiscal, environmental, education, transport and energy policy all have a role to play.

Table 5.2. Country examples of policies supporting supply-side conditions for breakthrough innovation

Type of policy	Policy examples
Costs of development and scaling	
Risk financing to develop, produce and scale breakthroughs incl. venture capital and dedicated funds.	Australia's Clean Energy Innovation (approx. USD 130 million [AUD 200 million] to support early stage and emerging clean energy technologies) and the Advancing Hydrogen Funds (approx. USD 190 million [AUD 300 million] for developments in this area) (EC/OECD, 2023[77]; CEFC, 2023[78]).
(Deep) tech start-up support programmes such as incubators and accelerator programmes that provide mentoring, networking opportunities incl. by promoting future tech forums, technology horizon scanning, linkages with pioneering firms, etc.	The Greentech Investment Programme in Estonia (2022-24) aims to invest approx. USD 22 million [EUR 20 million] as equity or convertible instruments in companies involved in green technology development through the SmartCap Fund from seed to growth phase (EC/OECD, 2023[77]). The European Innovation Council (EIC) was established in 2021 under the EU Horizon Europe programme with a budget of approx. USD 11 billion [EUR 10.1 billion] to support game changing innovations throughout the lifecycle, from early-stage research, to proof of concept, technology transfer, and the financing and scale up.
Investments in research and testing infrastructures	
Investments in **high-quality research and technical infrastructures** (incl. data gathering and analysis infrastructure).	The World Class Laboratories fund (2020-21) in the UK allocated approx. USD 380 million [GBP 300 million] to upgrade the scientific infrastructure across the UK to enable researchers to respond to societal challenges, including climate change (e.g. airborne sensors in London to monitor greenhouse gas emissions and an offshore wind testing lab at the University of Plymouth) (GOV.UK, 2021[79]).
Investments in **testing and demonstration facilities.**	Belgium is allocating funding to develop, on a new site, a generic infrastructure able to host the various installations necessary to carry out large-scale experimental tests on hydrogen technologies (EC/OECD, 2023[77]). Another example are the Testing and Experimentation Facilities for AI co-funded by the EU and Member States to support AI developers. These provide a combination of physical and virtual facilities, in which technology providers can get support to test their latest AI-based technologies in real-world environments.
Skills and capabilities	
Training and international skills attraction to engaging in breakthrough innovation research and prototyping.	In Israel, the High-Tech Human Capital Fund provides grants funding up to 70% of the costs of innovative programmes aimed at increasing the human capital in Israeli high-tech by attracting human capital from abroad and expanding training, specifically focused on advanced technological fields such as quantum, AI, and climate tech.
Build stronger science links & promoting cross-sectoral and cross-disciplinary collaborations (relates to imperative 2 on stakeholder engagement)	
Support multi-stakeholder **cross-disciplinary and cross-sectoral collaborations.**	In Australia, the Soil Carbon Data Program (2020-25) provides approx. USD 4.5 million [AUD 7 million] to support partnerships between scientists, industry and landholders to improve soil organic carbon data and measurement approaches.
Encourage the development of **academic spin-offs and start-ups.**	Collaborative Laboratories (CoLABs) in Portugal were launched in 2017 to create an interface between academia and industry and increase knowledge transfer and co-creation in key strategic sectors. There are currently 35 COLABS, each including at least one company and one public R&D partner.

Table 5.3. Country examples of policies supporting demand-side conditions for breakthrough innovations

Type of policy	Policy examples
Market creation	
Use public procurement to incentivise products with the potential to create new markets and be a frontrunner, which is not needed for established products (incl. procurement of innovations). **Expand civil society engagement in policy design and innovation processes**, which is an advantage but not as essential for incremental innovations. **Promote industry-government collaboration in shaping demand** for more environmentally friendly products (e.g. urban mobility). **Taxation** (such a carbon taxes) **or regulations** that mandate, for example, the use of low-carbon heating technologies in construction.	In Denmark, the Green Tax Reform adopted in 2023 aims to tax industrial companies based on CO2 emissions, and foster investments in green technology projects across the economy. In addition to a variety of tax instruments, it includes relief for firms investing in R&D and innovation (IEA, 2023[74]).
Investments in enabling infrastructure	
Improve digital and other infrastructures necessary for the scaling of breakthrough innovations (e.g. advanced digital infrastructures). **Support dialogue** between various areas of government and industrial and other stakeholders on infrastructure needs, funding models and use (incl management of risk-sharing).	The Zero Emission Vehicle Infrastructure Programme in Canada provides approx. USD 508 million [CAD 689 million] funding towards the deployment of electric vehicle chargers and hydrogen refueling stations across Canada.
Address regulatory and legal constraints (relates to imperative 3 on agility and experimentation)	
Expand regulatory sandboxes - limited form of regulatory waiver or flexibility that enables firms to test innovative technologies, products or services which are not yet fully compliant with the existing regulatory framework. (OECD, 2021[80]) **Support regulatory and policy agility**, in line with the OECD Recommendations of the Council for Agile Regulatory Governance to Harness Innovation and its supporting guidelines (OECD, 2021[81]).	In 2020, the Norwegian Data Protection Authority (Datatilsynet) introduced a regulatory sandbox that aims to promote ethical, privacy-friendly, and responsible AI innovation (OECD, 2023[52]). France Expérimentation allows for regulatory exemptions to facilitate testing of innovation projects in any sector. It allowed SEDE Environnement, a subsidiary of Veolia, jointly with the National Federation of Agricultural Holders' Union, to develop an innovative irrigation solution to fertilize crops reusing wastewater. See other examples under imperative 3.
Provide guidance to avoid co-ordination failure (relates to imperatives1, 2 and 4 on coordinated government, stakeholder engagement and directionality)	
Devise strategies/visions for countries, industries and regions. **Support cross-governmental collaboration** around key challenges. **Support ecosystem thinking** involving adjustments across the entire value chain (as e.g. deploying electric mobility models or on-demand transportation services).	See examples under imperatives 1, 2 and 4.

The case of Germany

Momentum has been gathering in German policy, industry and the broader STI community for pushing the German government to strengthen the country's ability to produce disruptive, breakthrough and radical innovation (Table 5.4). In a 2018 report, the presidents of the Max Planck Society and the Fraunhofer Institute, the chair of the board of trustees of the National Academy of Science and industrial leaders, called for reforming the innovation system to support more radical innovation (Harhoff, Kagermann and Stratmann, 2018[82]). This resulted in the creation in 2019 of SPRIND - the Federal Agency for Disruptive Innovation – to better support breakthrough innovations by funding promising pre-market projects selected through innovation challenges around specific themes. However, the agency's current size and budget may not be large enough to support breakthrough and disruptive innovation at a systemic level, and some administrative constraints reduce its flexibility of action.

Germany has been promoting innovation public procurement to accelerate the commercialization and market-building for high-potential inventions and developed a relatively robust policy-support framework for start-up growth. However, more efforts are needed to enhance procurement officials' ability to undertake innovation procurement and expand pre-commercial procurement. Providing young and small firms with the capital needed to scale remains challenging, reflecting in part the comparative underdevelopment of the venture and growth capital markets in Germany and the European Union.

Table 5.4. Policy support for breakthrough innovation in Germany

What is Germany doing? Some examples	**What could be done further?**
SPRIND Agency: Created in 2019 by the German government, its main task is to identify and develop research ideas that have the potential to lead to radical or breakthrough innovation, and to accelerate their commercialisation and diffusion. Among others, it issues innovation challenges on specific themes and supports winners further develop their disruptive innovation ideas. **Innovative Public Procurement**: Germany has introduced (1) the Competence Centre for Innovative Procurement in 2013, which establishes mechanisms to support pre-commercial procurement; and (2) innovation procurement programmes at the federal and regional levels (e.g. ZENIT agency of North Rhine-Westphalia). **Funding:** Start-up growth programmes include: (1) the Venture Capital for High-Tech Founders (*High-Tech Gründer Fonds*), which since 2005 has established itself as the central platform of federal funding for high-potential innovative start-ups; (2) the Future Fund (*Zukunftsfonds*), a USD 10.8 billion [EUR 10 billion] equity fund created in 2021 and managed by KfW, Germany's main state-owned investment and development bank, supporting the growth phase; (3) the long-running programme to support the founding of science-based start-ups (*Existenzgründungen aus der Wissenschaft – EXIST*), first established in the 1990s; and (4) INVEST, which promotes investments in innovative start-ups through acquisition grants since 2013.	Continue to develop SPRIND addressing institutional and legal constraints, including its complex oversight structures at birth that reduced flexibilities of actions, as well as limited resources particularly for scaling. Facilitate the development of university proof-of-concept funds to support academic spin-offs & start-ups (R 5.2). Support innovative procurement by creating coordinated innovation procurement programmes within public agencies at different levels (R 7.1), building capacity and incentives for public officials in charge (R 7.2) and for SMEs and start-ups to apply (R 7.3). Revisit the legal framework for German capital-collecting institutions to encourage investment in risky innovation (R6.1) and support efforts at EU level to scale (R 6.3). Expand tax incentives, especially those that allow private investors to offset capital losses against other income, or to exempt future profits when investing in the VC asset class (R 6.2).

Note: References in the "Would could be done further?" column in brackets, such as R5.2, refer to the reference of Overall Assessment and Recommendations chapter of (OECD, 2022[1]).

6 Conclusions: Next frontier for policy, open questions and way forward

6.1 The next frontier for policy: Establishing a future vision

Reaching the policy imperatives to support transitions requires countries to find ways to establish a shared and flexible vision of their future. The development of such a vision for 2030 and 2050 is the first recommendation of the OECD Review of Innovation Policy for Germany. Such a vision, created by a cross-ministerial, cross-institutional and cross-sectoral forum, should not be an inflexible planning exercise mandating actors to do or not do certain things. Rather, the vision is a key ingredient for defining the problems to be tackled, create a common reference point for actors working towards transition, bind together communities of interest and practice as well as focusing capital and other resources, and above all to set the 'directionality' of the technical and societal changes needed (Rotmans, Kemp and van Asselt, 2001[83]). A vision also helps ensure a framework for long-term policy action that is critical to reduce policy uncertainties that will hamper stakeholders to act (e.g. uncertainty as to how long provisions supporting green transitions will be in place).

While the precise institutional implementation or execution can be varied depending on country characteristics, it is important to emphasise that such a vision should not be "set in stone" as circumstances will change, nor should it be "dictated from top government or specific stakeholders" but explicitly be a consensual document. At the same time, it should be sufficiently specific to orient action rather than be so vague as to provide no clear guidance. An example of institutional arrangement for implementing such a vision, would be the creation of a public-private laboratory for policy experimentation, as recommended in the case of Germany by the OECD Review of Innovation Policy. The laboratory could implement a strategic foresight exercise to inform the vision and monitor developments and coordination challenges that may impede the transitions.

The vision is critical in realising all five policy imperatives. It is a core component in coordinating government since lack of an overall vision challenges understanding the contributions of respective parts. The vision is also a core element in engaging stakeholders by defining consensus on action and defining the specific long-term policy actions required. Moreover, without this articulated vision, agility and experimentation are hampered as proactive action requires knowing the goals that are to be reached and anticipating potential challenges ahead. The vision is also critical to informing the directions to set out and the nature of breakthroughs to welcome.

6.2 Open questions for STI policy analysis

Transitions studies focus on transition processes and their management but provide limited guidance on government policies in practice and would benefit from more in-depth analysis on the following:

- how to define and agree on the nature of needed transitions across different stakeholders, regions at national level in coordination with transnational thinking;
- how to orchestrate transitions effectively with actions taken up and scaled by industry, citizens, research institutions and government institutions;
- how to govern the effort in building transitions, and
- how to link it to government building legitimacy.

Endnote

[1] MOIPs are co-ordinated packages of policy and regulatory measures tailored specifically to mobilise STI to address well-defined objectives related to a societal challenge, within a defined timeframe.

[2] Examples from Germany and discussion on Germany are discussed in the OECD Innovation Policy Review of Germany (OECD, 2022[1]) and not repeatedly referenced throughout this report.

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