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TECHNOLOGY ASSESSMENT FOR EMERGING TECHNOLOGY

MEETING NEW DEMANDS FOR STRATEGIC INTELLIGENCE

OECD SCIENCE, TECHNOLOGY AND INDUSTRY
POLICY PAPERS

April 2023 **No. 146**

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OECD Science, Technology and Industry Policy Papers

This paper was approved and declassified by written procedure by the Committee for Scientific and Technological Policy (CSTP) on 23 March 2023 and prepared for publication by the OECD Secretariat.

Note to Delegations:

This document is also available on O.N.E under the reference code:

DSTI/STP/BNCT(2022)8/FINAL

Corrigendum

An earlier version of this report from April 2023 was revised:

Page 7, first paragraph after the bulleted list: replaced the word "forum" with "hub" so as to better capture the nature of international capacity that is needed to complement existing international TA activities.

Page 40, fourth paragraph: replaced the word "forum" with "hub" so as to better capture the nature of international capacity that is needed to complement existing international TA activities.

Page 48, endnote: replaced the word "forum" with "hub" so as to better capture the nature of international capacity that is needed to complement existing international TA activities.

Foreword

This Policy Report takes a broad view on contemporary Technology Assessment (TA) practices, challenges and new requirements. It represents the primary output under Module 1 (Technology Assessment and Foresight) of the CSTP Programme of Work and Budget 2021-22 intermediate output area (1.3.2.2.1) carried out by the Working Party on Bio-, Nano- and Converging Technologies (BNCT). The BNCT convened a Technology Assessment Steering Group in order to share experiences in regular meetings every 3 weeks in 2021 and 2022. The Steering Group provided a number of case studies as examples of TA in their respective countries and have, together, examined the contemporary TA practices and needs in a workshop held in Vienna on 8th and 9th June 2022, hosted by the Institute of Technology Assessment of the Austrian Academy of Sciences. Further, the group considered insights from other reports, including GAO's Technology Assessment Design Handbook (GAO 2021) and EPTA's report on COVID-19 (EPTA 2021), and events, such as the 2021 OECD "Technology in and for Society" Conference and the 2022 European Technology Assessment Conference. This work has also been generously supported by the government of Korea.

The annex to this Policy Report is located in a separate document: DSTI/STP/BNCT(2023)5/FINAL.

Technology assessment for emerging technology: Meeting new demands for strategic intelligence

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The rapid pace of technological change, coupled with a pressing need for solutions to address grand societal challenges and global crises, heightens the challenge for policy makers to develop science, technology and innovation policies at speed, in situations of high uncertainty and, in some cases, around potentially controversial technology fields. Technology assessment (TA) has a long history of providing decision-makers with timely strategic intelligence on emerging technologies. Current demands are pushing TA to evolve in order to fulfil diverse functions: to illuminate the societal, economic, environmental and other consequences of new technologies; to inform public opinion; and to guide research and development. Drawing on nine case studies, this report analyses the response of TA practices to these changing drivers and demands to support policies for new and emerging technologies. It also identifies a set of principles to guide good contemporary TA practice.

Keywords: technology assessment, strategic intelligence, technology futures, anticipatory governance, emerging technologies, responsible research and innovation, grand challenges, missions, transitions

Executive summary

The demand by decision-makers for strategic intelligence on new and emerging technologies has arguably never been higher given the rapid pace of technological change, growing needs in the spheres of health and environment and the need to anticipate and mitigate potential risks and negative consequences of certain technologies. Robust technology governance requires improving knowledge and intelligence to shape policies and inform decision making and to encourage technology for positive societal outcomes.

Technology Assessment (TA) is a major source of strategic intelligence for new and emerging technologies. TA is an evidence-based, interactive process to bring to light the societal, economic, environmental and legal aspects and consequences of new and emerging science technologies. In doing so, it informs public opinion, helps direct research and development and acts as a source of strategic intelligence to shape policies that both promote and govern new and emerging technologies.

This report provides a bird's eye view of contemporary TA practices and challenges and presents a range of TA types and situations to inform robust TA for policy and in the context of emerging technology governance.

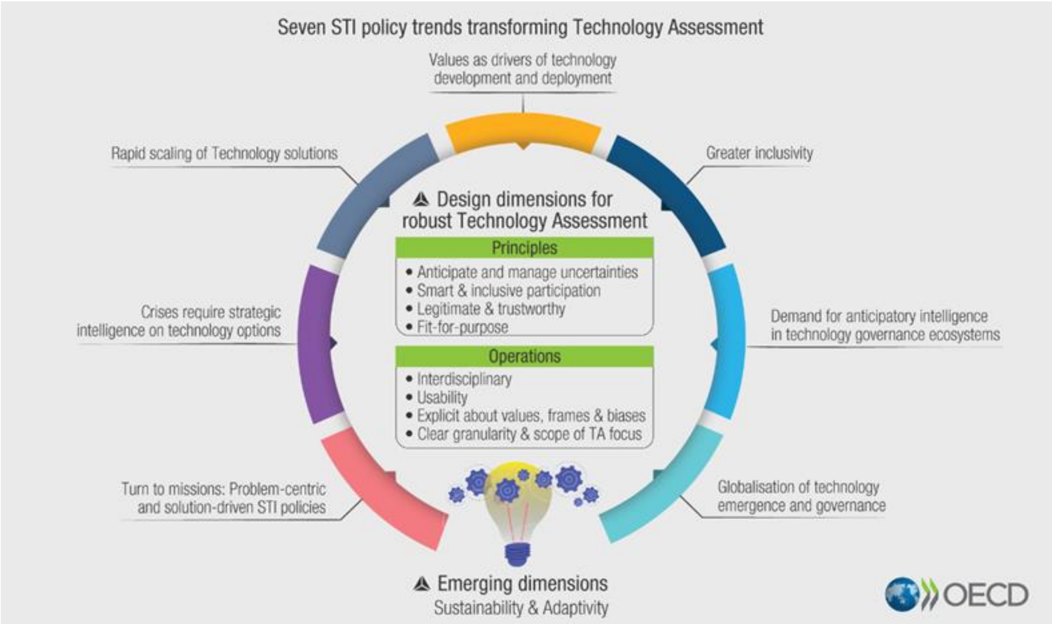
The comparative analysis of nine empirical case studies (see annex) provides three kinds of insights: details and examples of the main purposes of TA, the governance and policy trends that are driving new TA demands, and eight dimensions that can be considered as guidelines for robust TA.

The seven governance and STI policy trends that are driving TA to transform its practices, tools and approaches include:

- **Challenge and solution driven STI policies.** The need for solution-centric TA, rather than purely techno-centric TA, brings a range of new requirements: value-chain and systems centric perspectives are needed; thus, TA activities are increasingly tasked to analyse a portfolio of potential technology solutions and expand its evidence to include insights on whole value chains and systems.
- **Rapid crisis response.** Crises such as the COVID-19 pandemic exacerbated the need of decision makers for strategic intelligence on technology options. This requires TA practitioners to deliver rapid response TA that is of appropriate scale and scope, trustworthy and provided in a form that is usable by decision makers under periods of high pressure.
- **Scaling of technology solutions.** Demand to speed up scaling and deployment of technology puts major requirements on TA tools and practices. It necessitates early-stage anticipation and deep consideration of the deployment of new technologies. This includes the ethical, legal, environmental and societal implications of such deployment and feeding such anticipatory intelligence directly to STI policy.
- **Values as a more central driver of technology development and deployment.** Actors at both the country and international levels seek guidance and agreement on how to embed foundational values in technology to make innovation more responsible and responsive to societal needs. TA is well placed to draw out implications for these values, particularly around controversial technologies.

- **Greater inclusivity for more insights, building trust and good governance.** The inclusion of various stakeholders into the design and development of technology can be seen as an opportunity for TA and a means of building trust and transparency in the process of technological innovation. Having a long history of participation, TA is now challenged to provide tools and processes that can combine the inclusion rationales of sufficient representation and the harnessing of insights.
- **Increasing demand for anticipatory technology governance.** TA institutions, and the intelligence they produce should be integrated into broader governance ecosystems as well as coordinate with other future-oriented strategic intelligence providers.
- **The limits of national approaches.** The issues and topics that are subject to TA are becoming increasingly global in nature, including, for example, technologies to combat climate change, population growth, the impact of synthetic biology on ecosystems and gene editing. This means that TA insights would be more impactful if they were of an international scope, and patchwork policies and inconsistencies need to be avoided.

Infographic 1. Seven STI policy trends transforming Technology Assessment (see Figure 3. of report)



These seven trends are transforming TA in a number of ways, creating new demands and new requirements. Eight core dimensions have been identified (see infographic above) that act as guidelines for robust TA:

- **Fit-for-purpose.** Design of TA process should be aligned with key goals. This requires understanding exactly why the TA has been initiated and being clear about the envisioned outcomes of the TA activity.
- **Legitimate and trustworthy.** TA agents or institutions will be more effective as suppliers of strategic intelligence where they are considered “honest brokers” by diverse communities, independent of political influence and transparent about process and conclusions.
- **Clear granularity and scope of TA focus.** Robust TA requires clarity on the granularity and level of inquiry. Each form of perspective (techno-centric, value-chain, system perspective, etc.) requires a different range of expertise, evidence, tools and processes.

- **Smart and inclusive participation.** Which stakeholders are included and how they are included must be carefully designed and fit-to-purpose, based on a number of constraints (resources, scope and time available).
- **Interdisciplinary.** The nature of emerging and converging technologies and their consequences requires an expanding and combinatorial range of insights and disciplinary knowledge.
- **Explicit in terms of values, frames, and biases.** It is important for TA practitioners to diagnose the values and framings of participants within TA exercises, as well as being aware of their own biases.
- **Anticipatory and managing uncertainty well.** TA must be anticipatory and clear about the timeframe of its assessment. TA for emerging technologies must manage uncertainty over multiple timeframes.
- **Producing useable intelligence.** TA should connect to well-defined audiences through clear messaging, materials that are easy to digest and timeliness to inform policy at the right time with clear connection to the decision-making process.

Coordination and collaboration with different communities developing strategic intelligence on new and emerging technologies—particularly with a view to tools, methods and processes—could help provide better knowledge of technology as a public good and as a resource for collective action. An international forward-looking technology assessment hub might facilitate the exchange of strategic intelligence products and processes for global anticipatory governance of emerging technologies. Such a hub could facilitate exchange of intelligence, foster cooperation and provide an interface between intelligence producers and policy.

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1 Introduction

TA as a key source of strategic intelligence

Technology policy requires useful strategic intelligence to harness the benefits and reduce or mitigate the potential risks of new and emerging technologies. Strategic intelligence is useable knowledge that supports policy makers in understanding the relevant aspects and scope of the impacts of science, technology and innovation, and their potential future developments (Kuhlmann 2002, Robinson et al. 2021). Useful intelligence is essential for technology governance to develop strategies and policies to encourage technology for common good.

Technology Assessment (TA) is an evidence-based, interactive process to bring to light the societal, economic, environmental and legal aspects and consequences of new and emerging science technologies. In doing so, it informs public opinion, helps direct research and development and acts as a source of strategic intelligence to shape policies that both promote and govern new and emerging technologies. For example, TA can help define research and innovation agendas (Yoshizawa 2016) and facilitate international coordination for technology development to address societal grand challenges (Ely et al. 2014).

TA is conducted for a variety of sometimes overlapping reasons. It is deployed to anticipate potential impacts of new and emerging technologies to avoid surprise and allow for risk and uncertainty management and to produce useful knowledge to inform policy makers with regards to new and emerging technologies. It is produced to guide innovation and technology development towards societal goals by informing and shaping agenda setting and bringing to light key values and norms in the relationship between technology and society. In this way, it might help democratise the development of science and technology.[1]

Another key role of TA in today's world is to provide practical guidance in the governance of emerging technologies, a challenge that has risen on the international political agenda. The latest OECD work shows that anticipation is a key governance design criteria for emerging technology governance where TA plays a major role in supporting it. In fact, there is an increasing demand to anticipate new and emerging technologies as is visible in the recent key technology summits and initiatives, including France's Technology for Good initiative (Tech For Good Summit, 2020), the UK's Future Tech Forum under its 2021 G7 Presidency (HM Government, 2022), the initiative on Democracy-affirming technology launched in President Biden's Summit on Democracy (The White House, 2021), and a new Global Forum on Technology at the OECD. Moreover, governments are looking towards new and emerging technologies for solutions to contribute to key societal challenges in light of many current crises from the global COVID-19 pandemic, the energy crises in Europe and local effects of extreme events linked to climate change. Therefore, TA can be a key source of strategic intelligence for informing and shaping the governance of emerging and converging technologies.

As the report will make clear, TA can help support an anticipatory form of technology governance, which can be defined as the process of exercising political, economic and administrative authority through the mobilisation of future-oriented strategic intelligence to shape the development, diffusion and operation of technology in societies. Technology governance can consist of norms (e.g., regulations, standards and customs) and of strategic agendas and roadmaps for development and deployment of technologies (OECD 2018).

Report roadmap

The goal of this report is to provide a bird’s eye view of contemporary TA practices and challenges and to present a range of TA types and situations to inform robust TA for policy and in the context of emerging technology governance. This report is structured in four parts. Section 2 introduces TA, its origins and three traditional purposes for undertaking TA activities. Section 3 provides insights on seven trends, challenges and drivers of STI policy and technology governance, which are triggering new requirements and demands for strategic intelligence on new and emerging technologies. Section 3 also provides examples of how TA is being mobilised to address these new requirements and demands. Section 4 presents dimensions to consider when commissioning or undertaking TA in these difficult contexts. Section 5 provides a discussion and outlook for TA as a key source of strategic intelligence for the evolving needs of STI policy and technology governance. The report annex details nine case studies that are the empirical basis for this report.

2 Technology Assessment: What is it and how is it mobilised?

Background on TA

Informally, TA has been in operation since the dawn of science and technology policy by considering future implications when applying novel technologies. Formally, TA began 50 years ago with the establishment of the Office for Technology Assessment (OTA) for the U.S. Congress[2] with a mission to identify and consider existing and potential impacts of technologies and their applications in society. Noting that technologies were becoming more extensive, pervasive and impactful, the OTA placed an emphasis on the anticipation of the consequences of new technological applications – requiring robust and unbiased information concerning the societal, political and economic effects of such technologies.

Parliamentary TA institutions also emerged in Europe, following in the footsteps of the OTA. For example, the Netherlands Organisation for Technology Assessment (NOTA) was established in 1986 to inform the Dutch Parliament on the developments and potential consequences of new technologies. NOTA was subsequently renamed the Rathenau Instituut and remains an influential source of TA today. Another example is the Office of Technology Assessment at the German Bundestag (TAB), which was founded in 1990 to provide independent advice to the German Parliament on developments and consequences of scientific and technical change.[3]

The 1990s and 2000s have witnessed a proliferation of Parliamentary TA institutions around the globe and an increased recognition of the important role TA plays. In 2018, the U.S. Congress recognised that the scope of technological complexities had continued to grow significantly and there was a need to bolster capacity of, and enhance access to, quality, independent science and technological expertise, particularly in light of the fact OTA had closed in 1995.[4] Therefore, the U.S. Government Accountability Office (GAO) created the Science and Technology Assessment and Analytics team (STAA) with a focus on producing TA.

Whilst the term "Parliamentary TA" captures a large portion of TA activities, TA and TA-like processes have diversified with different (or expanded) objectives and are conducted in a variety of situations and settings. One such evolution is the expansion from expert-oriented TA activities (as seen in the TA activities of the OTA) to more *participatory TA* approaches.[5] Participatory TA acknowledges that underlying values, such as democracy, sustainability and equality, should be part of the TA process and therefore focuses on including a variety of relevant stakeholders that will be affected by new and emerging technologies (Hennen 1999, Delvenne and Rosskamp 2021).[6]

Other evolutions emphasise the important role of TA in achieving anticipatory governance, particularly with the aim of building societal capacity to *steer* emerging technologies at an early stage. A number of techniques emerged in the U.S. and Europe that focus on arming researchers and innovators with tools to undertake TA and use its outputs in real-time. These techniques include, but are not limited to, *real-time TA* and *constructive TA* (CTA).

- Constructive TA (Rip and Schot 1998, Rip and Robinson 2019) was developed in Europe as a tool to manage technology development under conditions of high uncertainty. CTA mobilised social science insights by analysing dynamics of emergence and the co-evolution of technology and society in a technology domain, identifying the variety of "futures" that are being mobilised by a range of stakeholders and creating socio-technical scenarios exploring what could happen. Such scenarios act as a platform for interaction between stakeholders in workshops to (a) reflect on ethical, societal and legal implications of emerging technologies, making explicit values of various stakeholders, and (b) identify strategies to steer research in a desirable and responsible way.
- Real-time TA (Guston and Sarewitz 2002) originates in the US and features iterative TA in the process of technological development and social science perspectives in the training and activities of researchers.

Purposes of TA

The core objective of TA is to produce good and useable strategic intelligence that informs the governance of new and emerging technologies. In doing so, each TA exercise fulfils specific purposes providing evidence for specific governance questions and policy needs. Three broad purposes of contemporary TA can be identified: (i) inform policy on key technology trends, (ii) gauge societal views so that they might better inform technology policy, and (iii) building and steering responsible technological and industrial agendas.

Informing policy on key technology trends

One of the most fundamental functions of TA is to improve the understanding of emerging technologies, their state-of-the-art nature and their potential economic, societal or environmental consequences. When addressing emerging and converging technologies, such as synthetic biology, neurotechnologies and quantum computing, TA must grapple with high degrees of uncertainty along multiple dimensions. Therefore, TA is important for structuring disparate and unclear information and translating this into usable information to inform decision-making.

Institutionalised TA does not have to sit within the legislative branch but can rather advise the executive branch, ministries and specialised agencies. One example is the Novel and Exceptional Technology and Research Advisory Committee (NExTRAC) at the U.S. National Institutes of Health (NIH). The NExTRAC reports directly to the NIH Director (Director) and provides recommendations and a public forum for transparent discussions on new and emerging biotechnologies along with any ethical, legal, social, economic and health issues associated with their development and deployment (more information see Box 1).

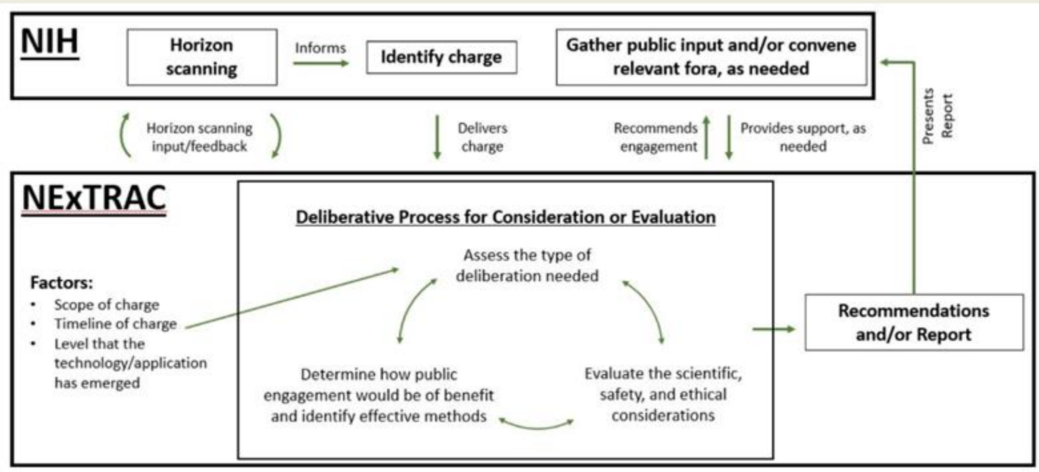
An example of a recent NExTRAC activity is the *Gene Drives in Biomedical Research Working Group*, which considered whether existing biosafety guidance is adequate for contained laboratory research utilizing gene drive technology and conditions (if any) under which NIH could consider supporting field release of gene drive-modified organisms. The exercise involved a dedicated workshop that was open to the public and made available online.[7] Going forward, NExTRAC recommended, in 2020, a framework for systematic TA of topics of interest that can be mobilised as a method for future NExTRAC efforts.

Box 1. The Novel and Exceptional Technology and Research Advisory Committee (NExTRAC)

The NExTRAC is composed of up to 25 members, and ad hoc working groups may be established to address a director's charge. NExTRAC incorporates a participatory element: according to a Framework developed by the Committee, public deliberation may be warranted when progress in the development of a novel biotechnology or technology application indicates it is likely to advance to the point of emergence and implementation within the next 5-10 years (or sooner).

In December 2020, the NIH Director created a working group of the NExTRAC dedicated to describing effective approaches for horizon scanning and conceptualizing a framework for consideration of scientific, safety, ethical and social issues associated with areas of emerging biotechnology research that would guide future NExTRAC activities. The potential deliberative process for NExTRAC that was developed (see Figure 1 below) involves iterative biotechnology horizon scanning by NIH, incorporating input from diverse groups on technology trends and potential convergence of technologies that may lead to new opportunities and risks. The iterative horizon scanning allows the identification of potential technologies (or convergence/development/applications of technologies) that could inform a "charge" requiring further deliberation. As visible in Figure 1 below, the process provides a flexible framework for future NExTRAC consideration or evaluation that can be applied for a range of charges delivered by the NIH. More details on this process can be found in the section 9 of the annex.

Figure 1. Potential Deliberative Process for NExTRAC Consideration or Evaluation



Source: Novel and Exceptional Technology and Research Advisory Committee. Report to Establish a NExTRAC Framework. 2020. https://osp.od.nih.gov/wp-content/uploads/NExTRAC-Framework-Report_FINAL_508.pdf

Another example of TA to inform policy on key technology trends is the assessment of technologies and approaches that could increase the speed and reduce the cost of vaccine development after the outbreak of the Covid-19 pandemic. For example, the US GAO's Assessment of Vaccine Development Technologies (see section 8 of the annex) study revealed nine policy options, which were themselves assessed for relevance and further elaborated as strategic intelligence that was made available as policy options for consideration (see Box 2).

Box 2. A selection of policy options to address challenges in vaccine development (GAO)

In June 2020, GAO began a TA that describes various technologies and approaches applicable to developing vaccines for infectious diseases, including the technologies and approaches for research and development, pre-clinical and clinical testing, and manufacturing. This work also examined the economic landscape and incentives for vaccine development.

At the time, the U.S. had just over 2 million reported COVID-19 cases and 103,000 deaths. Americans had begun to see the spillover effects on the economy as millions lost their jobs because of stay-at-home orders and business closures. Vaccines, which protect people from disease by preparing the body to respond to an infection, were acknowledged to be an important tool for individual and public health, and the U.S. Department of Health and Human Services (HHS) had allocated nearly $5.5 billion to support efforts related to COVID-19 vaccines and therapeutics (GAO 2020).

In the TA exercise, 16 technologies and approaches that had the potential to improve the ability of the U.S. to respond to high-priority infectious diseases were identified and analysed. The technologies showed different levels of maturity, promised different ways of improving the vaccine development process and posed different challenges—technically, organisationally and economically (for example, through the financing of development and deployment of the novel technologies identified).

To provide useful strategic intelligence for the U.S. Congress, the STAA developed a report that identified a selection of nine policy options that could be used to address vaccine development challenges. Three examples are provided below. Policy options are identified and accompanied with an assessment of the opportunities to be gained by pursing this policy option, along with some considerations to take into account, should the policy option be pursued.

Table 1. Three policy options for addressing the challenges of vaccine development for infectious diseases

Policy Option	Opportunities	Considerations
Improve preparedness Policymakers could provide support for public-private partnerships to strategically address potential pandemic pathogens identified as priorities. These partnerships could, for example, develop and test vaccine candidates that may provide protection from pathogens with pandemic potential.	This early development could provide a coordinated foundation that can be mobilized in an emergency. Such an approach could speed vaccine development, as well as potentially reduce risk for vaccine researchers and developers when it comes to questions of safety, efficacy, and manufacturability.	The lack of certainty of the commercial market and government funding for vaccines against pathogens with pandemic potential may be too risky for the private sector to undertake.
Further support development of data standards Policymakers could further support coordinated efforts to obtain the views of all stakeholders and to develop standards for health data and their use in clinical trials	Integrating researchers' needs into the standards development process could better ensure the necessary data are available. Access to high-quality data in a standardized format may allow streamlined patient recruitment for clinical trials	Expanding access to patient heath data requires attention to ensure privacy. Developing and implementing standardized data formats and IT infrastructure is time-consuming and costly.
Evaluate factors that inhibit vaccine investment and mechanisms to increase it Policymakers could collaborate across sectors, such as government, academia and industry, to conduct a systematic evaluation of factors that inhibit developers from investing in new vaccines	A clear understanding of the range of factors discouraging vaccine investment would provide the basis for effectively addressing those factors	Collaboration between policymakers and other stakeholders to obtain all relevant viewpoints can be time-consuming, and it may be hard to reach a consensus

Source: GAO-22-10437; see Annex for more details of the case study or see full report at Vaccine Development: Capabilities and Challenges for Addressing Infectious Diseases | U.S. GAO

By providing information and evidence, TA educates decision makers about potential technology trends, and can also act as a global resource for a variety of governance actors as well as the general public. The studies undertaken by GAO's STAA and the reports of the NExTRAC are provided online and add to the reservoir of TA intelligence that can be tapped to shape policy and inform debate. For example, for STOA's exploration of the societal concerns surrounding genome editing in crops (see annex section 2), policy options were mobilised from an earlier study by the Rathenau Instituut and further explored through an online stakeholder engagement exercise.

It is important that such strategic intelligence is robust, independent and that the processes behind the production of such information are transparent. Box 1 shows the proposed deliberative process for NExTRAC, emphasising deliberation and transparency (including making the meetings available online). GAO has developed a Technology Assessment Design Handbook, outlining key steps and TA design choices that should be taken to produce robust and trustworthy TA (GAO 2021).

Gauging societal views through deliberation

Certain forms of TA have an important convening function: they bring together different stakeholder groups, which not only stimulates public and political opinion forming on societal and ethical aspects of technology but may also foster public trust through engagement and inclusion. So-called "Participatory Technology Assessment" refers to a set of tools, approaches and processes of assessing socio-technical issues by proactively including a variety of stakeholders in a process of deliberation and assessment (Joss and Bellucci 2002). Such stakeholders include non-governmental organisations, organised critical groups, patient associations, trade unions, technical experts, religious representatives, industrial actors, civil servants and representatives of civil society. Participatory TA draws on the variety of perspectives, frames and stakeholder contexts to explore the potential effects of new and emerging technologies, as well as to promote the democratisation of technology.

Participatory TA emerged in a number of countries in the 1980s. For example, the consensus conference approach pioneered in Denmark by the Danish Board of Technology places citizens at the centre of deliberations around new technologies and the potential consequences of their further development and deployment (Klüver 1995). In the Netherlands, the Constructive Technology Assessment (CTA) approach was developed as a way of bringing different stakeholders together in a participatory process with the aim of integrating these perspectives into the design, development and governance of new and emerging technologies (Schot and Rip 1997, Daey Ouwens et al.1987). Recognising that prediction is a tough task for early-stage and highly uncertain fields of technology development, the Dutch TA agency NOTA (now Rathenau Instituut) proposed that another approach would be to shift the focus away from relying on prediction in its strictest sense and stimulate a process of reflexive anticipation through controlled speculation (controlled because the speculation is based on past evidence of the underlying dynamics of technology emergence). Constructive Technology Assessment (Constructive TA) is an approach that embeds controlled speculation into the world of research and development (for example, research teams at universities, firms or industry consortia). Embedding Constructive TA is a means to integrate into technology strategies: (i) the diverse shaping factors of technology development and deployment, the variety of innovation stakeholder perspectives that could shape the direction and fate of technology emergence and an understanding of how impacts from new technologies are generated and shape the economy and society more broadly (Schot and Rip 1997, Daey Ouwens et al.1987).[8]

Participatory TA approaches are particularly relevant for probing, as well as for clarifying hopes and concerns around potentially disruptive and controversial technologies. An example might be the DNA-dialogue held in the Netherlands (Box 3), a project in which the Rathenau Instituut coordinated technical inputs and moderated 27 public dialogues on the controversial topic of Human Germline Genome Editing (HGGE). Human germline genome editing is where embryos are genetically altered to enhance or inhibit certain traits. The altered embryos are then inserted into the uterus of the mother-to-be to develop and be born. This example of an inclusive form of TA involved a wide range of actors from different social groupings. The approach aimed to (a) inform a diverse range of stakeholders about the opportunities and uncertainties surrounding HGGE, as well as the societal and ethical issues it raises, (b) to bring people together to articulate and discuss their hopes, questions, wishes and concerns, and (c) gather and synthesise the rich diversity of perspectives and considerations around this controversial technology with the aim of informing political decision-making about HGGE and stimulating further societal reflection.

The DNA-dialogues were part of a broader political re-evaluation of the Dutch Embryo law that also pertains to the creation of human embryos for research purposes and expanding the indications for embryo selection. Whilst the formal political discussion about altering the Embryo law has not taken place at the time of preparing this report, the results of the societal dialogue on HGGE are provided as a source of synthesised policy-relevant strategic intelligence on societal hopes and concerns surrounding the future use (or not) of HGGE.

Box 3. Societal dialogue on human germline genome editing in the Netherlands

The DNA-dialogue consisted of three phases: (1) a preparatory phase, (2) the organisation of public dialogues, and (3) the analysis and synthesis of the results. During the preparation phase, the Rathenau Instituut produced a report that gave an overview of HGGE, providing evidence about the societal and ethical issues surrounding HGGE and details of the political and public debate about HGGE in the Netherlands (Baalen et al. 2019). The Rathenau Instituut developed the report to provide a robust and independent baseline that could provide clear information for the communication and tools to be developed to engage with those who would participate in the public dialogues.

As a preliminary synthesis of the information gathered, Baalen et al. 2019 provided a list of 10 lessons that would inform the design and scope of the dialogues. In addition, four techno-moral scenarios were drafted that imagined a different society in 2039 based on four application strategies for HGGE. These scenarios act as a tool to specify and explicate the potential consequences of HGGE for individuals and society as a whole, as well as the underlying moral dilemmas—providing “living worlds” with which dialogue participants could engage. Three of these scenarios were transformed into short, animated movies—so-called “techno-moral vignettes”—that were used during the dialogues to provoke reflection and discussion.

In the second phase of the project, 27 moderated dialogues were organized. In order to include a wide variety of perspectives in the dialogues, some were aimed at a broad, general audience while others specifically targeted certain groups such as patients, school children, medical professionals, the elderly and people with a migrant background or with lower literacy. Each dialogue was tailored to the target audience (for example, starting the discussion with a case study that was relevant to the specific group, or using language that is easier to understand).

The discussion of these themes was then summarized in terms of the values, concerns, hopes and expectations of participants, as well as the conditions under which they deemed reproductive HGGE to be acceptable.

The results of the DNA-dialogue provide a rich insight into the various perspectives, considerations, questions, hopes and worries surrounding HGGE in Dutch society. They have been published in a final report that also includes six recommendations to policymakers for further reflection and decision-making, which has been handed over to the minister of Health, Welfare and Sport in January 2021. This report is in Dutch but a summary was published in CRISPR Journal in 2021 (Baalen et al. 2021). Additionally, a "consolidation report" (in Dutch) containing lessons learned and instructions for organizing successful future societal dialogues has been published.

Source: Baalen et al. 2019 & 2021 and case study (see annex).

In another example relating to biotechnology, New Genetic Technologies (NGTs) have reopened discussions about the promise of genome editing as a solution to sustainable agriculture and the reduction of pesticides. *Societal missions*, such as the European Green Deal, require transformative changes in agricultural systems where technologies may provide the answer. Gene modifying technologies are strictly regulated in the EU under the GMO Directive. The definition of a GMO within the Directive, that a GMO is "an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination" may lead to ambiguities when considering the advancement of NGTs—it could be argued that NGTs accelerate a potentially naturally-occurring mutation. Moreover, questions about tracing the effects of the use of NGTs in crops, given the subtle nature of the modifications, raise concerns about whether the current GMO directive is fit-for-purpose.

With these questions in mind, STOA recently conducted an online stakeholder engagement exercise with the aim to explore and articulate societal hopes and concerns surrounding genome editing in crops in order to support decision-making by the Members of the European Parliament (MEPs). The four-stage exercise (see Box 4) has resulted in a publication that provides key strategic intelligence for MEPs on societal hopes and concerns in the regulation of genome editing in crops, intelligence that can be considered in the anticipated debates on genome editing.

Box 4. Online deliberations on genome editing in crops (STOA)

STOA recently conducted a four-stage online stakeholder engagement exercise that explores a number of policy scenarios regarding the use of NGTs in the genome editing of crops.

The first stage was to identify key information and illustrative scenarios of the future with regards to the development of genome editing of crops. Utilising the STEEPED approach (van Woensel 2020), the identification of key information mobilised seven lenses: societal, technological, economic, environmental, political/legal, ethical and demographic. In addition, the STOA activity mobilised existing TA strategic intelligence in the form of Policy Scenarios already developed by the Rathenau Instituut (Habets et al. 2019)

The second stage was to invite relevant stakeholders to respond to the survey. The survey therefore took the form of a questionnaire prompting reactions to four hypothetical policy options based on those proposed by the Rathenau Instituut: 1.) no revision of the GMO directive, 2.) deregulation of NGT products that contain no foreign DNA, 3.) a risk assessment approach based on the level of genetic change, and 4.) a level-based approach where evaluation would be based on societal and ethical values. Identification of stakeholders to be targeted with the survey was done through the use of the STEEPED lenses mentioned above.

In the third stage, the hopes and concerns gathered through the survey were synthesised and consolidated into four documents, one for each policy scenario. Stakeholders were then invited to participate in an online workshop, not to assess which scenario was better or worse, but to clarify whether the hopes and concerns where clearly articulated for each scenario.

The fourth stage was the production of a report that captured the four revised documents on the policy scenarios. The original format (grouped per policy option) obtained as a result of the workshop is also presented in the annex (STOA 2021). Examples of concerns expressed included general concerns about the EU policy-making process, the practical implementation of new legislation and societal safeguards, social acceptability and consumers' freedom of choice, traceability and potential health and environmental risks.

Source: STOA (2021) and STOA case study (see annex section 2)

Building and steering responsible technological, innovation and industrial agendas

Whilst policymakers can mobilise TA to gauge public hopes, concerns and values through deliberation and societal dialogue, they can use TA to build technology and innovation investment strategies.

Building national competitiveness through targeted investment in different areas of science and technology research and development is a key aspect of STI policy, and TA can play a supportive role. For example, following the Portuguese Resolution of the Council of Ministers, the Ministry for Science and Higher Education commissioned the Portuguese Foundation for Science and Technology (FCT) to develop fifteen thematic research and innovation agendas. One of them, the Industry and Manufacturing Agenda 2030, mobilised experts from R&D institutions and companies to prospect the potential opportunities and challenges for the Portuguese research and innovation system in the medium and long-term (Box 5).

The main goal of the agendas was to foster collective reflection on the knowledge base needed to pursue the scientific, technological and societal goals in the thematic area in question. Therefore, a bottom-up approach was facilitated through an inclusive and dynamic process involving experts from academia, research centres, companies, public organizations and civil society.[9]

Box 5. The Portuguese Industry and Manufacture Agenda 2030

The Industry and Manufacture Agenda 2030 assessed different enabling (emerging and converging) technologies from the point of view of potential impact to industry and manufacture in the following years. In this way, the technology assessment process was approached from an applications perspective, trying to identify the potential impacts in the area in connection to the state of maturity of the technologies, as well as the challenges and goals to aim at. The main overall goal is fostering global competitiveness of Portuguese industry.

The process involved the identification of (a) the main challenges or foster innovation in industry and manufacturing in Portugal, (b) global trends that could shape the industry and (c) five broad priority domains for the agenda.

Examples of main challenges to foster innovation in industry included, but was not exclusive to, the need to incorporate knowledge and new technological competencies into firms and integrating Industry 4.0 and circular economy concepts into a range of industries. Key global drivers included climate change, competition for natural resources, the rise of social responsibility in industry and manufacturing globally and trends such as digitalisation and its ramifications on manufacturing and business models.

As a result of this agenda setting TA process, an overview of the most promising technologies to have a strong impact on Portuguese industries was established. Along with these shared goals, and a collectively agreed upon timeframe, the direction and pace of coordinated development was achieved as strategic intelligence for setting STI policy in Portugal.

Source: More details of this case can be found in the annex section 5.

TA can combine societal deliberation and reflection with agenda setting, and this is visible in the current plans for a Biotechnology Assessment in Korea. The Korean government has recognised biotechnology as a core growth engine since the 1990s and has been systematically investing in R&D since 1994 through its First Basic Plan for Biotechnology Promotion. By the late 1990s is became apparent that, alongside additional R&D investment, it was important to improve the social acceptability of technology if biotechnology would fulfil its promise of benefiting the people of Korea. Tensions emerged between incumbent industries and those exploring and advancing biotechnology solutions, and citizens' concerns around genetically modified organisms began to emerge leading to formal and informal technology assessments (Joss 2002).

Currently, the Korean Biotechnology Promotion Act to revitalise the industrial ecosystem has included a discussion about promoting the development and utilization of general-purpose innovative technologies such as synthetic biology and gene editing, and to accompany this activity with reflections on ethical and regulatory issues related to biotechnology. As a result, the "Act" was amended in 2020 and the technology assessment for biotechnology was institutionalised (Act 10, see Kim et al. 2020). The bill contains the content that 'technology assessment on technologies that are expected to have a large social and economic ripple effect among major technologies in the biotechnology field should be implemented.' In such a way, the amendment of Act 10 of the Biotechnology Promotion Act incorporates elements of Responsible Research and Innovation into the heart of biotechnology promotion and governance. The TA will take place during 2023 and 2024.

Another example of TA in a strategic planning process is visible in the U.S. National Nanotechnology Initiative (NNI). Launched in 2000, the NNI currently involves more than 30 departments and independent agencies with a range of research and regulatory roles and responsibilities. As part of the 21st Century Nanotechnology Research and Development Act, the NNI must update its strategic plan every five years. Assessments of current state-of-the-art developments and capabilities in nanotechnology research and development, assessment of potential future directions and public engagement are key parts of the updating of the NNI Strategic Plan (NSTC 2021)[10].

TA and TA-like processes for building technology and innovation agendas, may mobilise a variety of tools and approaches, but centre on connecting societal needs and values into STI policy and governance. As opposed to the previous type of TA focusing on eliciting societal hopes and concerns, this form of TA aims at identifying technologies to invest in, to drive research, to boost industries and to lead to desirable societal impacts.

3 Governance and STI policy trends influencing contemporary TA

STI policy is being pressured to react to a number of factors that are driving new demands for strategic intelligence on emerging and converging technologies. Policy and governance trends such as mission-orientation, crisis preparedness and inclusivity are but a few of the trends that are shaping the intelligence needs of STI policy. In the following subsections, seven trends, challenges and drivers of contemporary STI policy and technology governance are presented. For each trend, challenge or driver, examples are given of how TA is being mobilised to address these policy and governance needs.[11]

The turn to challenge-driven STI policies

Science, Technology and Innovation (STI) policy is increasingly pressured to direct research and innovation towards societal goals and to contribute to overcoming grand societal challenges. STI is challenged to provide solutions for these major societal problems, for example to respond to the UN Sustainable Development Goals (SDGs) or the European Commission's five Horizon Europe Missions. These challenges and goals are large scale in nature, often global, and comprise of multiple entangled systems, for example, the challenge of achieving climate neutrality in our cities requires solutions that can transform diverse areas such as mobility, energy production, energy consumption, waste management and behavioural change (OECD 2021, Robinson and Mazzucato 2019, Mazzucato 2018).

This shift puts new demands on TA—the perspective moves away from techno-centric anticipation of potential developments and associated impacts towards exploring portfolios of technologies, potentially at different stages of development, and potentially having different functions in the solution under exploration.

There are examples of TAs for problem-centric and solution-centric STI policies. For example, at the U.S. GAO, a number of TAs have been problem-centric. For example, TAs focusing on reducing freshwater use in hydraulic fracturing and power plant cooling, tracing the source of chemical weapons[12] and wastewater-based epidemiology.[13] Other examples can be seen at the Dutch Rathenau Instituut, with TAs focusing on problems such as tackling deepfakes[14] and cyber resilience.[15] Whilst there is still a prominence of techno-centric STI policies, problem- and solution-centric technology governance and STI policies are increasing, bringing with them many design trade-offs for TAs such as: how wide a portfolio of technologies to explore? How to articulate the potential solution(s) in the first place?

These challenges are amplified for TAs targeting technologies for achieving societal missions. Mission-oriented STI policies have a larger scope: missions such as "zero pesticide agriculture by 2040"[16] or "100 Climate neutral cities in Europe by 2030" (European Commission 2020) combine the exploration of portfolios of technological (and perhaps non-technological) solutions with socio-technical systems such as agricultural systems or urban mobility systems. Thus, if STI policy is to be part of more mission-oriented policies, then appropriate mission-relevant strategic intelligence on emerging and more mature technologies is needed—laying down the gauntlet for TA practitioners.

Related to the trend above, solution-centric, and mission-oriented TAs require a *socio-technical system or value chain perspective*. Be it, for example, the whole vaccine development chain (see Box 6 below) or facilitating sustainability through developing a circular economy.[17] Such system or value-chain centric TA requires multiple expertise and insights—creating major challenges in identifying and mobilising diverse stakeholders to participate in the TA (see the Inclusivity trend later in section 3.5).[18]

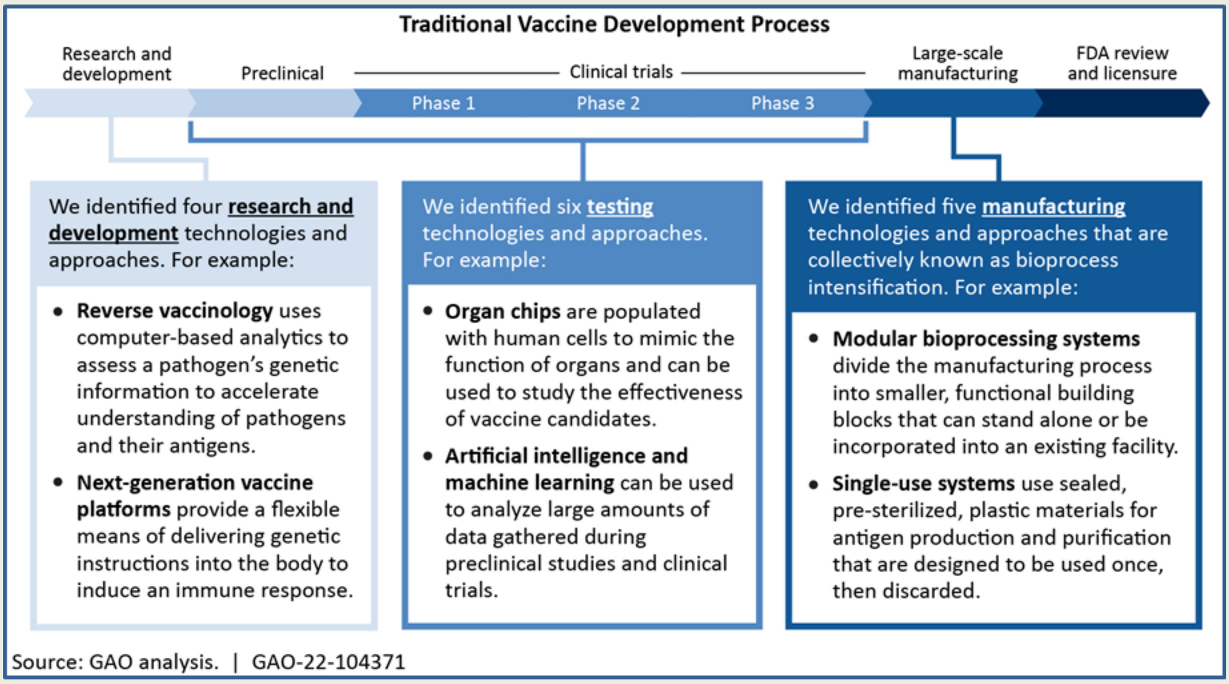
Box 6. GAO's Assessment of Vaccine Development Technologies

An example of a value-chain or systems perspective is visible with the GAO Assessment of Vaccine Development Technologies (for further information, see the case study in annex section 8). Here, the focus was to identify key technologies that could enhance the ability of the U.S. to respond rapidly and effectively to high-priority infectious diseases through rapid vaccine development.

With its primary focus on the innovation ecosystem, the Vaccine Development TA mapped each innovative technology to a phase in the vaccine development life cycle (Figure 2 below).

Taking a value-chain and systems perspective, GAO's STAA provided strategic intelligence for policy around a particular problem: rapid vaccine development. However, the focus is still on the role of science, technology and innovation on the vaccine development process, therefore, the system-level study was complemented by techno-specific studies. In this case, a series of one-page technology description were provided as appendices to the TA report, which allowed the readers to quickly reference detailed information about each technology, including its level of maturity, how it works and potential applications.

Figure 2. Vaccine technologies and approaches used during vaccine development



Source: More details of this case can be found in the annex.

Crises requiring strategic intelligence on technology options

Crises have exacerbated the need for strategic intelligence on technology options by decision makers. This need challenges TA practitioners to rapidly deliver strategic intelligence on emerging and converging technologies to STI policy makers. For example, the COVID-19 global pandemic required rapid STI responses to provide Personal Protective Equipment (PPE), vaccines, defibrillators as well as knowledge about the virus, its spread and mutations. Governments around the globe had to deal with a crisis with high scientific uncertainty, making rapid decisions that would affect national populations. Without access to relevant and timely strategic intelligence, STI policies may be misguided or ill informed, which could hinder local and global responses to crises.

During the early stages of the COVID-19 crisis, existing TA advisory bodies were tasked to provide guidance and advice for decision makers on how to tackle the rapidly evolving pandemic with a view to responsible research and innovation. For example, in the Region of Lombardy (Italy), which was the first region in Europe to have a substantial number of cases of COVID-19, the existing Regional Forum for Research and Innovation,[19] a body of ten experts advising on responsible research and innovation in the regional STI strategy, provided "Flash Recommendations on the COVID emergency" within weeks of the outbreak of the virus (10 April 2020). Recommendations included how to mobilise citizen expertise, build trust during the crisis and issues around responsible scaling of solutions.

During later stages of the pandemic, Parliamentary TA agencies from the European Parliamentary Technology Assessment (EPTA) network,[20] developed a country comparison of experiences of TA and decision-making during the pandemic, leading to a number of recommendations. One key insight from the study included the potential ongoing effects of the digitalisation of education and work during the pandemic leading to the amplification of inequalities in some countries. Another key insight was that a lean healthcare system and "just-in-time" healthcare delivery comes at the expense of pandemic preparedness and key (informed) choices must be made if pandemic preparedness is to become a policy priority (EPTA 2021).

An assessment of technologies and approaches that could increase the speed and reduce the cost of vaccine development is another example of TA in response to the COVID-19 crisis. In June 2020, GAO's STAA undertook a TA to identify and describe the technologies and associated challenges for vaccine research and development, vaccine testing and vaccine manufacturing. Its report in November 2021, included an analysis of economic factors that hinder investment in vaccine production and deployment (see Box 6 and annex section 8).

Crises can spur "rapid response TA" and can highlight a need for expanding knowledge on a particular domain to improve preparedness against further crises (the case of rapid vaccine development by GAO's STAA). Anticipating on crises such as the effect of climate change on various critical systems, such as food, water and agriculture, or the effects of war on energy supplies and trade, are key and growing areas for STI policy. Therefore, TA is being challenged to provide support for technological and governance solutions to pressing issues—as the COVID-19 pandemic has demonstrated; TA is pressured to move rapidly in response to, or in advance of, global or local crises.

The heightened need for rapid scaling of technology solutions

The urgency for rapid and transformative solution development, made explicit in the trends described above, requires early consideration of the scaling and deployment of technology solutions. In his speech at the Technology in and for Society multi-stakeholder conference, convened by the OECD on 6-7 December 2021, Director General of the European Commission Jean-Eric Pacquet drew attention to the need for rapid deployment of technologies to solve burning issues within society and to drive economic growth. In the same vein, at the same event, Prof. Sebastian Pfotenhauer emphasised that technology and innovation policy instruments are insufficiently equipped to facilitate the scaling of innovations at the necessary pace—there is real-time pressure to anticipate as a continuous process from small scale to large scale (OECD 2022a). However, continuous anticipation and feeding the insights from such anticipations into policy making requires considerable resources.[21]

This demand for speeding up the scaling and deployment of technology puts major requirements on TA tools and practices. It necessitates early-stage anticipation and deep consideration of the deployment of new technologies, the ethical, legal, environmental and societal implications of such deployment and feeding such anticipatory intelligence directly to STI policy. TA outputs should be available at the right time to inform policy and decision makers on responsible and rapid roll out of new technologies.

In a similar vein, the speed of technology emergence and potentially undesirable proliferation also necessitates rapid TA that informs real time STI policy and technology governance more broadly. This brings up a key challenge for emerging and converging technologies: when is the right time to be conducting a TA exercise? At very early stages there are major uncertainties, and it is unsure whether the technology under focus may evolve to provide benefits or be a major concern, or both. Often, the pace for technology uptake is also unknown. TA at too early a stage may not be relevant for major policy actions because the technology is not yet significantly impacting society and/or other more pressing issues may be higher on the policy agenda.[22]

Values as a driver of technology development and deployment

Technology and society co-evolve; hence it is becoming increasingly recognised that technologies are tightly entwined with, and are shaped by, norms and values of society. Recognising that shaping technology to reinforce certain values in society, in recent years governments and public agencies have been highlighting the importance of making core values explicit in technology governance.

Certain values of democratic governance, such as human rights, security and sustainability, are becoming core elements of STI policies and technology governance fora. This is visible in recent key technology summits, for example, in partnership with the private sector, the French government's Technology for Good initiative has seen 75 digital technology firms sign up to key values of internet freedom, openness, transparency and neutrality.[23] Also the UK's Future Tech Forum, as part of its 2021 G7 Presidency, has underlined openness (of the internet), maintaining democratic values of inclusivity and human rights and safeguarding against digital authoritarianism.[24] This was echoed in December 2021, with the U.S. White House launch of its Democracy-Affirming Technology initiative.[25]

As described in the STOA case study (see annex section 2), one of the fundamental pillars of the European Union is to ensure that through democracy, citizens can freely express their views and have a say on their future. Therefore, for making evidence-based policy choices about new and influential technologies it is essential to factor in not only the scientific evidence, but also the societal context in which the technology would be applied, making explicit the underlying values, exploring shared and differing values and incorporating them into the promotion and governance of technology development and deployment.

This approach was pursued by the Rathenau Instituut in its programme of TA activities entitled "Value-Directed Artificial intelligence" (Box 7 and annex section 4). Over a period of approximately five years, the Rathenau Instituut has progressively urged the Dutch and European government and relevant societal stakeholders to build a governance system for using Artificial Intelligence (AI) in a value-based way in various domains, ranging from health care, justice or public administration. The need for such advice was evident: the risk of AI dramatically affecting people's lives has painfully materialized with the 'Child Allowance Affair': between 2013 and 2019, the Dutch government wrongly accused an estimated 26 000 parents of making fraudulent child benefit claims, based on algorithms using demographic variables, such as migrant background. Families were ruined, financially and emotionally (Frerks and Terpstra 2021).

If value-driven technology development and deployment is a growing trend, a key question is how to *do* value-driven governance of new and emerging technologies?

Box 7. Value-directed artificial intelligence in the Netherlands

In September 2014, the Dutch Senate asked the government to invite the Rathenau Instituut to investigate the desirability of a committee that can advise on the ethical aspects of the digitization of society. The motion was based on the suspicion of members of parliament that the trend of digitization compromising some important public values and human rights.

A key TA report produced by the Rathenau Instituut, called “Urgent Upgrade” (Kool et al. 2017), which discussed ethical and societal issues raised by digitalisation of society, alerted politicians and other stakeholders that a clearer strategy was needed for building a stronger governance system that would be able to safeguard a range of fundamental public values, such as privacy, autonomy, safety and security, control over technology, human dignity, equity and equality and balances of power.

Advising that the Netherlands, and Europe, should aim for a digital society where no one is excluded, the Rathenau Instituut made the case that the public sector, the private sector and civil society organisations must steer digital society in such a way that greater focus is placed on people and values. The case for a practical approach to value-based AI was presented in a report “This is how we put AI into practice based on European Values” (Jong et al. 2019).

Noteworthy in this case study, is the role of a TA institution in shaping the governance, partly through predefined strategies (observing from their vantage point a need for more explicit value-based approach to technology development) and partly from the demand of the Dutch parliament and government.

Source: More details of this case can be found in in section 4 of the annex.

Greater inclusivity for more insights, building trust and good governance

The inclusion of relevant stakeholders in STI is seen as key for providing democratic legitimacy, building trust and for improving the development and deployment of new and emerging technologies.

The trend for more inclusive STI captures a broad range of aspects and activities. For example, one rationale for increased inclusion of various stakeholders including civil society, relates to knowledge and expertise. Such “distributed intelligence” can be captured through integrating a variety of stakeholders and insights into TA activities (Kuhlmann 2002). This can be SME associations, civil society organisations, non-governmental agencies, trade unions, consumer groups, patient associations, etc.

Another element of inclusion relates to representation of those that may be affected by a new technology, those that may benefit and those that may not. Addressing potential inequalities that may arise is essential for fair and equitable development and deployment of a new technology (Robinson, Simone, & Mazzonetto 2021). This brings up a challenge for TA: there is a need to strike a balance between relevant expertise for conducting robust TA and representativeness. This requires making explicit choices on experts on the TA topic, on the one hand, and representation of wide array of stakeholders in deliberative democracy, on the other hand.

Another rationale for increasing inclusion in the development of STI is to build trust in science and technology activities and governance. According to a 2021 OECD survey on drivers of trust in public institutions,[26] trust in governmental institutions is under pressure and there is a recognised need for greater citizen involvement, transparency of governance decisions and inclusion of civil society.

Part of this trend is visible in the case study of the U.S National Institutes of Health (NIH). It highlights that building trust around new biotechnologies and their relationship with the future of healthcare requires transparency and deliberation. As one of many engagement mechanisms undertaken by the NIH, the agency can gather public input for the NExTRAC and its working groups or initiate forums, workshops and requests for information. It also encourages transparency of NExTRAC activities through public broadcasting of advisory committee meetings and elicits feedback on draft reports. At the time of preparing this report, the NExTRAC Working Group on Data Science and Emerging Technology is consulting a variety of stakeholders on attitudes and perspectives with respect to the sharing of data to advance biomedical research (see annex section 7 for more details).

Online tools and methods are enabling the possibility of reaching more stakeholders along with reducing costs per participant. In the STOA case described earlier (see Box 4 and annex section 2) surveys plus online workshops were mobilised to gather the hopes and concerns of a range of stakeholders regarding the regulation of genome editing of crops (STOA 2021). Interestingly in this case, STOA partnered with another TA organisation, the Danish Board of Technology (DBT), who had a long history and expertise in using online participatory tools, which could be mobilised for STOA's needs.

Major challenges accompany the drive for inclusive TA:

- Resources (staff and budget) to be able to access and integrate a variety of stakeholders.
- Time, in particular if there is an urgent need for rapid-turnaround TA, there are considerable pressures to identify and integrate relevant stakeholders. The STEEPED approach (see Box 4 and Van Woensel 2020) provides lenses to help gain a balanced representation of stakeholders.
- Address the implicit biases of each stakeholder group when participating in TA exercises and addressing the development and deployment of new and emerging technologies. Each stakeholder group brings their own framings and interests to participatory TA exercises. The challenge is to make these framings, positions, and interests explicit as part of the TA exercise (van Woensel 2019).

Increasing demand for anticipatory intelligence in technology governance ecosystems

New and emerging technologies, by their very nature, promise revolutions in a variety of industries and fuel hope for tackling some of the world's grand societal challenges. The societal, economic and environmental impacts of new and emerging technologies harbour both hopes and concerns around potential benefits and risks. For example, developments in gene drive technologies (Nelson et al. 2021), DIY biology (Meyer and Vergnaud 2020) and Artificial Intelligence (GAO 2021) have recently triggered a series of global discussions about the future societal, economic and environmental impacts as well as potential governance approaches (OECD 2018).

The potential need and demand for emerging technology governance are gaining salience. For example, the development of new tools and technologies enabled by synthetic biology, coupled with concerns during the COVID-19 pandemic and a plethora of science fiction and popular media discussions, has increased interest and discussion about governance of synthetic biology. Anticipatory technology governance is seen as key to support technology development for societal good, whilst safeguarding against, or preparing mitigation strategies for, potential negative societal impacts of new and emerging technologies.

Timely and robust strategic intelligence is increasingly sought to inform emerging technology policy, thus resulting in a growing demand for TA in a broader anticipatory governance ecosystem. In doing so, insights from TA and other forms of strategic intelligence are becoming anchored in these systems as they provide vital forward-looking information on emerging technologies for decision makers.

TA institutions and agents build capacities overtime, spot trends, react to emerging issues and anticipate demands for strategic intelligence for policy and governance. For example, the Rathenau Instituut in the Netherlands built a programme of TA exercises over a five-year period in response to observing that deeper insights into the ethical and societal implications of the digital transition in many areas of the economy and society will be needed. Originally triggered by the Dutch Senate, the Rathenau Instituut became a central player in an ecosystem of governance actors, with the questioning, and redesigning, of the Dutch governance system on AI (Kool et al. 2017, Jong et al. 2019). Through a programme of TA, the Rathenau Instituut built a core knowledge base on AI trends and governance ramifications, as well as being able to offer advice on the governance system itself—proposing a value-based approach to AI development and deployment (see Box 7 and annex section 4).

Another example is the evolving nanotechnology risk governance ecosystem in Austria and TA's key role in it. Originating with the NanoTrust project in 2007, the Institute of Technology Assessment (ITA) at the Austrian Academy of Sciences (ÖAW), over time acted, and continues to act, as a keystone in the national ecosystem and as a carrier and orchestrator of a programme of governance activities across multiple agencies and actors. Since the early/mid-2000s, regulators and Environmental, Health and Safety (EHS) experts struggled with an abundance of uncertainties regarding the nature of nanomaterials and nanotechnologies and tried to keep up with the rapid developments in nanoscience and nanotechnology research and development (Rose et al. 2019). NanoTrust (see Box 8 below), originally designed as a TA project of two years, developed into a programme of activities commissioned through six rounds over a 17-year period, acting as a node in a network of nano risk governance actors. Maintaining close ties with the Austrian nanotechnology governance system, NanoTrust was also able to have continuous interactions and consultation with EHS and risk expertise as well—allowing for an agile, and adaptable TA process that could react to the rapidly evolving situation of nanotechnology and integrate anticipatory intelligence into its governance. As a key part of the Austrian nanotechnology governance system, NanoTrust has become almost an institution in-of-itself, providing robust and independent information with a high degree of trust and legitimacy.

TA institutes regularly take on the role of key intermediaries within a wider ecosystem of actors and institutions governing emerging technologies. In such cases, TA institutions strive to act as "honest brokers" (Pielke Jr. 2007) by convening different kinds of stakeholders to eventually deliver guidance and options to policy and other decision makers. This "broker role" is important but, as the group agreed, a difficult chair to sit in because it requires neutrality and impartiality, facilitating discussions, being trustworthy to diverse communities and providing legitimacy and credibility to discussions and decisions on technology governance.

The programme and ecosystem approach to TA allows to follow the emergence of new technologies and accompany, and influence, the co-evolution of technology and society—building capacities that can be sustained beyond individual TA projects and initiatives. The participants of the workshop also reflected that an ecosystem perspective allows TA programmes to identify topics of general societal interests and build critical mass of strategic intelligence on these particular topics, and to respond flexibly and with agility to emerging issues.

Box 8. NanoTrust: A keystone TA in a nano-risk governance ecosystem

With the rapid development of nanotechnologies since the early 2000s, policy makers required a sound scientific basis for decision making. In the mid-2000s, there was growing concern about the lack of understanding of the potential risks of nanomaterials and the debate on environmental, health and safety issues, particularly in the production and use of nanoparticles, became high on the agenda of relevant EHS authorities (Shelley-Egan et al 2018). In 2006, ITA was assigned to produce a status report on the international EHS and ethical, legal and societal implications (ELSI) of research regarding nanotechnologies and nanomaterials by the Austrian Ministry of Traffic, Innovation and Technology (BMVIT). Based on this report, in 2007 the NanoTrust project at the Austrian Academy of Sciences, dedicated to nano-safety and governance, was funded by the BMVIT.

An important driver of the project was the idea of building a network of experts with the capacity to produce independent and robust information regarding EHS issues and potential risks of nanomaterials and other nanotechnologies. The rationale for anticipatory governance in nanotechnology drew on earlier experiences with new and emerging technologies, for example, in biotechnology and genetically modified organisms (particularly in the food area) that caused heated debate and controversy.

As a TA approach, NanoTrust drew on elements of Constructive Technology Assessment (CTA), whose underlying rationale is not only to assess development trends and potential impacts of new and emerging technologies, but to use that intelligence to influence directions of development (Rose et al. 2019, Robinson 2009). In this way, the NanoTrust, renewed five times over 17 years, plays an active role in the Austrian Nano Governance System contributing to pre-emptive risk management through anticipatory and constructive technology assessment.

Source: Rose et al. 2019, Pavlicek et al. 2019 and dedicated case study (see annex section 1)

Anticipatory technology governance relates also to the activities of those involved in the design, development and deployment of new and emerging technologies, in addition to formal government activities. Recent proponents of Responsible Research and Innovation (RRI) of new and emerging technologies argue that embedding responsibility and accountability into the activities of researchers, firms and other actors that shape and steer new and emerging technologies, will enhance the potential of new technologies for good and decrease the likelihood of undesirable effect of technologies (Shelley-Egan et al. 2018, Owen et al 2021). For example, Jo Husbands (2018), using the case study of a controversy over dual use research with highly pathogenic avian influenza, presents responsibility and accountability in research as a key element of safeguarding against dual use of new and emerging technologies in the life sciences.

The globalisation of technology emergence and governance

The development of technology occurs across the globe, in national STI and governance systems and in different socio-cultural contexts. As economic development and globalisation progress, there is a need for strategic intelligence that can capture global and local technology development and deployment dynamics, as well as the diversity of impacts when these new technologies are embedded in society and compare and contrast the different governance mechanisms and approaches that occur.

There is an increasing recognition by the TA practitioner community that assessment of emerging and converging technologies cannot be addressed at a national level but requires a pan-national or global perspective (Hahn and Ladikas 2019). Not only does technology develop and move rapidly from the local to the global, but also the scope of challenges such as food security, climate change, sustainable energy and sustainable manufacturing transcend national boundaries.

Two examples of pan-national networks of TA institutions are:

- The European Parliamentary Technology Assessment (EPTA network). Composed of 26 members and associate members, the EPTA network shares insights, reports and practices specifically in TA for gauging public opinion and exploring the societal ramifications of new and emerging technologies (see Section 2.2.2. on TA for deliberation).
- The "globalTA" network,[27] which was set up to actively foster cooperation between institutions active in TA and TA-like processes, to develop a global framework for impact assessment of technologies as well as supporting challenge-driven anticipatory governance of new and emerging technologies.

4 Eight dimensions to design robust TA

The changing STI policy landscape and technology governance requirements—as elaborated in the previous section—have implications for the design of TA exercises, good TA practices and successful TA institutions. This was subject of collective reflection and the shared exploration of case examples (see annex) by TA experts and policy makers in a dedicated project steering group (2021-22). In fact, the group identified eight dimensions to consider when designing robust TA. They represent the outcome of this collective reflection on central ideas and design principles that inform and drive good TA practices. The eight dimensions, described in the following sections, can also be considered as important requirements when commissioning or evaluating contemporary TA activities.

As each TA objective and context differs, it should be noted that each dimension can be approached in a different way and their importance may vary. With this in mind, the dimensions below provide a general guide to what is needed to achieve effective and impactful TA.

Table 2. Dimensions of robust Technology Assessment practice

Design dimension	Description	Considerations
Fit-for-purpose	TA process should be aligned with key goals, for example to: • Deliberate and gauge opinions • Inform key trends • Build agendas Shape and steer governance	Identify the different steps and activities that will fulfil the key goals of the TA to determine which methods and tools are best suited to achieve the overall goals. Consider unpacking (1) *why the TA has been initiated* and (2) being *clear about the envisioned outcomes* of the TA activity.
Legitimate and trustworthy	The TA process and its outcomes should be legitimate and trustworthy to diverse communities. It is important for the TA agent or institution to be seen as an "honest broker", independent of political influence and transparent about process and conclusions.	Conducting trustworthy TA, particularly when facing controversial or inconvenient evidence, requires maintaining independence and transparency. Transparency regarding uncertainty, what is known and what is unknown about potential evolutions of the technology and associated benefits and risks, is also key to undertaking trustworthy TA for both TA intelligence users (e.g., policy makers) and those participating in TA activities (e.g., civil society).
Clear granularity and scope of TA focus	Robust TA requires clarity on the granularity and level of inquiry, e.g.: • technology-centric (e.g. quantum computing) • value-chains focus (e.g., seafood chain from sea to fork) • socio-technical system perspective (e.g., mobility systems, energy distribution) Hybrid levels of analysis (e.g., novel technologies for different stages of clinical trial chain)	Scope and granularity of the TA are tightly connected to the goal of the TA exercise, which in turn relates to the eventual user of the intelligence produced by the TA. Each form of perspective (techno-centric, value-chain, system perspective etc.) requires a different range of expertise, evidence tools and processes. For example, whilst a quantum computing TA could rely on researchers and developers in the quantum field as core experts for the TA, a TA of technologies that could

		revolutionise the clinical trial chain would require expertise on a range of new technologies such as organs on chips, artificial intelligence, modular bioprocessing systems etc. (see Box 7 for more examples).
Smart and inclusive participation	Which stakeholders are included and how they are included must be considered, based on a number of constraints: • resources available (staffing, funding) • scope (identifying relevant social groups based on topic and scope of TA) • time available (if short on time, may have to limit and focus inclusion)	Consider processes such as the STEEPED approach (Box 4 and Woensel 2019) as a means to identify a variety of stakeholders such as firms and industry associations, research communities, civil society organizations, citizens, user groups (e.g., patient associations), trade unions, financial actors, regulatory agencies etc. It is also important to consider first order and second order impacts of new technologies. Be aware of, and lower, barriers to participation. Consider a diverse set of stakeholders as an advisory group on the TA process itself, to help identify bias. Consider the trade-offs between virtual and physical inclusion.
Interdisciplinary	The nature of emerging and converging technologies and their consequences requires an expanding range of insights and disciplinary knowledge.	Consider mobilising social scientists (sociologists, economists, legal scholars, management scientists) in both the framing and execution of the TA. Consider incorporating hybrid natural and social scientists in TA teams – whose ambidextrous skill set can facilitate TA practices.
Explicit in terms of values, frames, and biases	TA practitioners should diagnose the values and framings of participants within TA exercises, as well as being aware of their own biases; only then can transparent, independent, and useful strategic intelligence be produced.	Consider the use of TA and foresight handbooks and guidelines to consider pros and cons and avoid framing bias (e.g., TA analysts being excited about technologies).
Anticipatory and managing uncertainty well (at the right time)	TA for emerging technologies has to manage uncertainty over multiple timeframes: • Near-term (5 years) • Mid-term (10 years) • Longer-term (15 years +) Thus, TA must be anticipatory, and clear about the timeframe of its assessment.	Consider mobilising other anticipatory tools and approaches for exploring technology futures in the appropriate timeframe: horizon scanning, data mining, scenario development, co-design, impact assessment. Consider when is the right-time to undertake TA activities – too early may trigger public concerns on a topic of great uncertainty, too late may make the findings unactionable or redundant.
Producing useable intelligence	Key issues for utility of TA outputs for decision making include: • Having a clear message • Produce material that is easy to digest • Being timely so as to inform policy at the right time • Having a clearly articulated connection to decision making process	Consider the target audience for the intelligence that is produced from the TA activity. Clearly articulate the relationship between the TA activity and decision-making (both in terms of key actors and timing of the decision-making).

Fit-for-Purpose

A key characteristic of good TA practice is that the TA is fit-for-purpose, i.e., aligned with key goals. There can be multiple goals for TA exercises, as the previous sections illustrated. Therefore, it is essential to clarify the demand for TA and the potential supply of TA intelligence. Hence, unpacking (1) why the TA that has been initiated (the "demand") should be coupled with (2) articulating the envisioned TA outcome (the potential "supply"). Key questions to help articulate the envisioned outcomes include: What are the main goals of the TA? Are the objectives clearly defined upfront or is the exercise explorative?

On the demand side, there are multiple reasons why a TA is initiated, they include:

- gauging public perceptions of risks and ethical concerns on a particular technology (e.g., see the DNA-Dialogue case in Box 3 and section 3 in the annex)
- creating shared research and innovation agendas by anticipating desirable and undesirable developments of a particular technology domain (see the Portuguese Industry and Manufacture Agenda 2030 case in Box 5 and section 5 of the annex, see also the Bio TA in Korea case study in section 6 of the annex)
- addressing an urgent societal challenge by exploring potential solutions (see the GAO's Assessment of Vaccine Development Technologies case in Box 6 and section 8 of the annex).

On the potential supply, examples of envisioned outcomes could include identification of potential ethical risks of emerging technology (e.g., 3D bioprinting), anticipating innovation challenges in upscaling of technology innovations (e.g., nano-enabled bioplastics or synthetic biology using biofoundries) or building trust and transparency in technology development (e.g., principles for the responsible development of neurotechnology innovation).

Legitimate and trustworthy

Making the TA process and its outcomes legitimate and trustworthy to diverse communities is a difficult but essential design parameter. For example, one challenge for many TA exercises is to ensure that outcomes of participatory TA exercises are included in governance decision-making processes. This is a major challenge requiring decision-makers to be open to suggestions from societal stakeholders (citizens, civil society organisations, etc.) and also to foster trust from societal stakeholders that their input will be integrated and actioned. In heated debates, such as those around genetically modified organisms (Marris and Joly 1999) building trust between those who commission the TA and the TA participants, as well as ensuring legitimacy of the TA process and outcome, has been a major challenge but essential for good TA practice.

Having clear, transparent, and inclusive "arenas" for sense-making can build legitimacy around TA practices and contribute to building trust. Certain forms of TA, for example participatory TA, have an important convening function: bringing together different stakeholder groups which not only stimulates public and political opinion forming on societal and ethical aspects of STI, but also helps to foster public trust through engagement and inclusion. Consensus around a topic does not need to be the aim of a participatory TA activity, and some TA scholars and practitioners have described participatory TA activities as arenas where sense making takes place of both the controversies as well as for revealing how different stakeholders perceive the focus technology and its place in society (Rip 1986, Delvenne and Rosskamp 2021).

Maintaining the independence of the TA agents and transparency of TA processes is vital, particularly when addressing potentially controversial topics or when facing inconvenient evidence. Transparency can be with regards to being honest about the uncertainty surrounding the technology developments and how technology and society may change. This means that a key characteristic of good TA practice is articulating what is known and what is unknown about potential evolutions of the technology and associated benefits and risks. For example, the GAO Assessment of Vaccine Development Technologies included a description of both the opportunities and considerations that should be taken into account when considering the potential actions policymakers could take to effect change (see annex). This is key for both TA intelligence users (e.g., policy makers) and those participating in TA activities (e.g., civil society).

Another aspect is to maintain neutrality of the TA agent or institution or be transparent about the normative role of the TA activity (Rose et al. 2019). The trust that is invested in institutions and individuals who conduct TA often necessitates feelings of confidence around legitimate and trustworthy TA. Such confidence can be based on (a) the past performance of the institutions commissioning or doing the TA and (b) the relationship between the TA exercise and actions taken outside the TA exercise "in the real-world" (Marris et al 2008).

Clear granularity and scope of TA focus

Designing relevant, robust and useful TA confronts TA practitioners with crucial choices such as the identification and selection of emerging and relevant topics. TA practitioners often face a tension between breadth and depth vs. resources which originates from the need to assess a wide variety of emerging technologies thoroughly. A key part of this stage is the framing of the object of concern: an emerging new technology, a more mature technology that has the potential to be used in novel ways, a societal challenge that requires the scoping of new technology solutions, etc.

For example, is the assessment perspective technology-centric (focusing on a particular technology), e.g., focusing on improving the functionality of the technology based on an improved understanding of user demands such as neurotechnology for marketing, nanotechnology for health applications, etc? Is the framing of the assessment perspective innovation ecosystem-centric (focusing on value chains and partnerships), e.g., focusing on questions like what needs to be in place for a successful nano-enabled sustainable packaging value chain? Is the framing of the assessment perspective at the sectoral or socio-technical system level, e.g., looking at transformations of mobility or energy production? Is the framing of the assessment perspective on solution or societal-mission centric, e.g., TA for rapid vaccine development in times of crisis or solutions to remove pesticide from agriculture?

In Korea's Bio TA case study (see annex section 6), the scope of the TA is biotechnology, and the biotechnology-related innovative ecosystem. It explores RRI issues inherent in multiple stages of technology emergence: the R&D stage, the industrialisation stage (or industrial application stage) and the utilization stage (end consumer) of major biotechnologies discovered through a horizon scanning process. For example, during the R&D stage, the level of transparency and openness of data collection and sharing infrastructure is crucially important. Moreover, during the industrialisation stage, there is a challenge of avoiding first mover advantages leading to a monopoly situation, closing down options for many industrial actors in this domain and potentially stifling innovation. Also, at the utilization stage, it is important to understand in advance what is the requirement for a safety management system that can garner consumer and user trust, with regards to the safety of the biotechnology-based product.

Clearly framing the TA perspective is key to evaluate the breadth and depth of the TA topic as well as identifying the resources needed to undertake the TA exercise appropriately. For example, the GAO Assessment of Vaccine Development Technologies (see annex section 8) followed their Technology Assessment Handbook to clearly define the scope of the work. This allowed the team to develop an initial understanding of the technology and the context around that technology, such as social, political, legal, and economic factors (see annex section 8).

Smart and inclusive participation

Selecting "appropriate" stakeholders is another important design dimension for the TA activity. Good TA practice includes clear methods for (a) identifying relevant stakeholders, (b) the consideration of the variety of incentives to encourage participation and (c) enabling open access to TA deliberations and activities (where appropriate).

Depending on the focus of the TA, the types of stakeholders or concerned groups will differ greatly. Which stakeholders are important to engage with and when? The decision mechanism for selecting stakeholders or experts to involve in the TA activity requires a clear rationale linked with the objective of the TA (the envisioned goal of the TA and its outcome) and the robustness of the TA (building trust and rigour through inclusiveness and smart selection of appropriate expertise). Since TA is sometimes linked to controversies, conflict between different stakeholder groups may occur, requiring this to be factored into the design and implementation of the TA exercise. There are a number of approaches and methods to help with identifying stakeholders for TA exercises, for example, the STEEPED approach (described in Box 4 and Van Woensel 2020) provides a useful guide to help gain a balanced representation of stakeholders.

Identifying stakeholders is one challenge, incentivising them to participate in the TA exercise is another. One good practice is to be clear about the benefits (rewards) of participation. Different societal groups have different motivations to participate in TA activities and thus may be incentivised to participate through different reward schemes. Another good practice for inclusion is to include participation in the synthesis of the outcomes of the TA activity. A practical example from the U.S. Government Accountability Office is to send participants an advanced draft copy of the TA synthesis report to collect comments. This is also an opportunity to explain to participants why some of their comments are not included. It is an activity that requires sensitivity as well as resources and time but can pay off in becoming transparent and gaining stakeholder buy-in (see annex section 8).

In the example of Bio TA in Korea (see annex), deep TA activities are planned to be implemented every other year. In years where no assessment is conducted, stakeholder engagement will be undertaken to (a) inform various stakeholders about the new and emerging biotechnology field and (b) to gain insights from the variety of stakeholders to inform the selection of subject area and focal target of the following year's TA. In this way, direct inclusion of stakeholder's shapes TA targets as well as informing on the technology, building trust and incentivising participation through the ability to shape the TA focus targets.

Passive participation through observation of the TA activities is another form, in addition to direct inclusion in TA activities. The U.S. National Institute of Health's NExTRAC takes the approach to make deliberations accessible online in real-time and after the event (see annex section 7). This enhances transparency and the potential for inclusion.

Interdisciplinary

The types of "expert" stakeholders involved and solicited for TA has been broadening from scientists and engineers to including the views of social scientists. This has not only established trust but has also enabled framing TA problems differently.

While multidisciplinary TA means that different disciplinary perspectives are gathered and explored at the same time, interdisciplinary TA explores the overlaps between disciplinary knowledge when doing research and analysis (Decker 2008). Transdisciplinary research can be defined as activities where participants from different scientific disciplines, as well as other actors, such as civil society and users, jointly develop concepts, methods and solutions to a common problem (OECD 2020).

The uncertainty around new and emerging technologies, along with the complexity of the potential co-evolution of technology, the economy and civil society, is revealing a need to further develop interdisciplinary TA approaches. For example, NanoTrust was funded as an interdisciplinary research project and cooperates with diverse scientific and non-scientific organisations. The commitment to mobilise interdisciplinary and transdisciplinary knowledge is specified, and is a requirement, in the NanoTrust contracts (see case study in annex section 1).

Explicit about values, frames and biases

The nature of TA is that a large number of stakeholders are brought together to explore potential new and emerging technologies and their impacts on their professions, their personal lives and the broader socio-technical systems and mechanisms that make up society. Naturally, different stakeholders will have their own perspectives on issues that are explored through TA practices and therefore it is important to understand (a) the perspective frames of professionals and lay persons involved in TA and (b) understand the variety of biases that may shape both the opinions that are voiced and the reactions to others. The range of biases include cultural and normative biases, self-interest biases and biases in how evidence is produced and mobilised.

Claire Craig (2018), drawing from her experience of risk management in the policy environment of the United Kingdom, describes how lenses of different actors play a key role in assessing new and emerging technology options. Craig provides the example of hydraulic fracturing for shale gas (fracking), where the British Royal Society and Royal Academy of Engineering report on health, safety and environment (EHS) risks, found that risks could be managed effectively in the UK, which directly informed (as evidence) the UK government's decision to continue exploratory drilling. When viewed through other lenses, there can be resonance and dissonance with the EHS lens. A global lens would evaluate fracking from perspectives such as global carbon budgets, energy pricing and security. A local lens would include perspectives as landscape changes and the impact of the increased amount of transport through the local region and the pollution (noise and air) this would cause, as well as considerations of biodiversity. This example of three lenses, by no means exhaustive, illustrates that it is important to make clear the framing and the biases inherent to the TA exercise in order to position the evidence and insights TA produces.

In the Korean case, Bio TA activities are managed by an administrative agency (see annex), however, the TA framework and the facilitation and communication strategy, are planned to be designed and implemented by a consortium of research institutes. The rationale behind this is (a) to reduce the risk of government bias that agencies under the administration may have, (b) to expand the pool of TA researchers and practitioners in Korea and (c) to catalyse the transfer of the results of TA to innovation policy researchers that can help draw policy implications more clearly.

In the earlier discussion of the characteristic of trustworthiness and legitimacy, it was highlighted that the TA agent should remain impartial and independent, the notion of Honest Broker is often mentioned as a characteristic of a TA agent. A number of analysts and TA practitioners have observed a seeming paradox: how can a TA agent remain neutral whilst also having an impact. One can argue that different forms of TA, different goals of TA, have a different degree of normativity. Since TA is generally conducted to have an impact, how do we manage this paradox? Grunwald (2019) suggests that the different "role concepts" of technology assessment should be addressed within the TA community to focus on the tension between the requirement that TA should have an impact but at the same time be neutral and distant. This is very much visible in Constructive Technology Assessment, where TA agents insert themselves into the world of technology developments to increase anticipation and reflexivity and to steer developments into desirable directions. Rip and Robinson (2019) reflect on this challenge and provide the "insertion methodology" to maintaining independence, making explicit normative stances and being embedded in technology development communities without "going native".

Thus, for robust TA, making explicit the values, frames and biases is essential, for both TA participants and the TA agents themselves. A number of resources are available to aide in making explicit norms, values and biases, for example, van Woensel (2019) proposes a "Bias Radar" to help spot and position various biases.

Anticipatory and managing uncertainties well

To be able to inform policy and to shape technology governance, it seems wise to undertake TA activities at early stages. However, at early stages of development, there is little knowledge about eventual outcomes of technological development and their effects, but the technology pathways are not yet entrenched, and steering is relatively easy. When technology developments have become more stabilised and are more visible, however, and criteria for assessment can be specified, developments will be entrenched and there are vested interests and stabilized practices, so it will be more difficult to change much about the technology (Collingridge 1980).

Some scholars and TA practitioners argue that this is too strong a dichotomy (Robinson 2010). In fact, the dilemma is visible within any innovation process where one has to shift from exploration to exploitation and foreclose options at a moment where still not enough is known. This analysis can be extended to later stages of the innovation journey where again options, now about markets, regulation and uptake and impact, will be foreclosed before enough is known to do this with certainty.

Recognition of the many choices (and by different actors) that are involved shifts the challenge from the strong dichotomy that Collingridge presents (and which can be heard as a message calling for technology governance) to a wide range of choices over time. With these choices, actors make their own assessments, address a variety of uncertainties and mobilise different forms of strategic intelligence to inform their actions.

TA can come in everywhere along the innovation journey and help modulate the overall process by introducing anticipation and feedback to actors facing their ‘little’ dilemmas of strategy articulation.

There is a further limitation of the original Collingridge dilemma, which is the absence of consideration of what would be desirable directions and impacts. There is a third horn, and the dilemma is actually a trilemma: at an early stage, it is not clear what the dimensions of desirability should be, because the promised novelty may well transcend existing ethical and political evaluations—technology and society co-evolve. By the time ethics and politics have caught up, *les faits sont accomplis*. The third horn (Robinson 2010) becomes a concrete demand for TA and for anticipatory technology governance more generally.

TA can also be understood as a 'reflexive space' where current assessments of technologies are stress tested with regards to future values and needs. For example, assessments currently made on the desirability of genetically modified crops to withstand drought, or the use of aerosols to cause clouds to be more reflective and lower atmospheric temperatures, may be evaluated differently in a future where the global average temperature is 1.5 degrees Celsius above todays, with the associated effects on food security and the environment.

With the above in mind, good TA practices must manage uncertainty, not only at the early stages of new and emerging technologies, but at later stages too, where there are a different range of uncertainties. There are a number of tools and approaches within TA as well as external to TA, such as Foresight, Tech Mining and anticipatory Impact Assessment, that can help here.

A number of key technology areas span futures greater than the usual time frame of TA exercises, for example, large infrastructure projects such as energy systems, urban transformations, mobility systems, nuclear power plants, etc. and nuclear power plants. For the latter, a key concern is to find solutions for radioactive waste management, an issue requiring multi-generational technology governance beyond 30 years. In a recent TA activity focusing on anticipatory governance, the Dutch Rathenau Institute, undertook a participatory TA activity assessing the issue of long-term radioactive waste management leading to a report for the Dutch Authority for Nuclear Safety and Radiological Protection (ANVS). Governmental decision-making about the management of radioactive waste from nuclear power plants encompasses large technical uncertainties, major public concerns, political preferences that differ across nation states and over time and international influences (Vries et al. 2015).

A number of pressing anticipatory technology governance activities require TA with an anticipatory governance perspective—traditional risk assessment is based on a large amount of evidence, where for emerging technologies, the evidence is not yet there. Thus, anticipatory governance approaches that can evaluate potential benefits and hazards in the longer-term is essential.

Incorporating impacts of new technologies on future generations of society is also a growing concern, raising questions of intergenerational justice as a core value. For example, gene drive technologies are emerging that promise to bias a particular trait being passed on to subsequent generations of living organisms. When gene drive modified organisms mate with unmodified organisms, the chosen trait becomes dominant in the subsequent generation population—gene drives spread engineered traits through a population at a rate much faster than is possible by “natural” inheritance (NExTRAC 2021). Such multi-generational and cascading effects may pose high risks along with the envisioned potential benefits (Nelson et al. 2021), benefiting from anticipatory governance with a multi-generational and long-term perspective.

Usability

An important role of TA is to structure disparate and unclear information and provide understandable interpretations to decision makers. Thus, good TA practice requires the capacity to translate between silos and turn insights into understandable language. For TA outcomes and processes to have an impact, a clear message and making explicit the connection between the TA outcomes and the connection to decision making processes are key.

Careful consideration of the target audience for the intelligence produced through TA is needed, as well as consideration of the audience’s absorptive capacity—how much time do they have to devote to assimilating TA intelligence? For example, in the case of GAO’s Assessment of Vaccine Development Technologies (see annex section 8), brief one-page summaries of key technologies being explored were provided, providing optional detail for the target audience of the TA intelligence. From the same case, another example of means to enhance the usability of TA intelligence is to provide policy options for consideration by the target audience, in this case, the U.S. Congress.

Enhancing the usability of strategic intelligence may sometimes require a further translation step into the language of the target audience. With regards to STI policy, a "policy lensing" approach has been developed to translate complex scenarios into the language of policy makers by mobilising policy priorities as a lensing device (Robinson et al. 2021).

In Korea's Bio TA (see annex section 6), although the main beneficiaries of the activities are ministries and high-ranking officials in biotechnology policy, it is also envisioned to develop a targeted communication strategy for the National Assembly and citizens more generally, to allow broader consideration of the outcomes of the TA work. Thus, audience specific materials will be tailored for the National Assembly and the general public to raise awareness, facilitate transparency and support broader societal reflection on biotechnologies in Korea.

Good TA practice includes the clear articulation of the target audience, appreciation of their absorptive capacity as well as their room for manoeuvre in terms of ability to mobilise the strategic intelligence for technology governance. For example, the GAO Assessment of Vaccine Development Technologies identified nine policy options which offer policymakers a range of possible actions that may enhance benefits or mitigate challenges. Although policy options do not endorse a particular course of action, the analysis shows that various policy options have trade-offs, with each potentially fulfilling certain goals more than others (see annex section 8 and Box 2).

Other increasingly relevant and emerging design dimensions

Two additional characteristics of robust TA were seen as increasingly relevant and could be considered as potential additions to the eight dimensions elaborated in this report.

One increasingly relevant dimension for robust TA is that TA activities should be sustained over time. Sustainability of TA projects and programmes allows for maintenance of a strategic intelligence reservoir that can be drawn upon when needed. For example, NANOTRUST (see annex section 1) maintained, and continues to maintain, a technology assessment capability on nanotechnology for over a decade, with clear ties to the Austrian Nano Governance Ecosystem. The sustained activity means that NANOTRUST is a legitimate source of strategic intelligence and can be responsive to the needs of the governance system due to its long-term anchoring. In a similar way, the Rathenau Institute, in its five-year programme of TA activities centring on value-directed artificial intelligence, built a capacity for analysing and developed an evolving knowledge base on artificial intelligence. Because of this capability, not only are they able to provide on demand strategic intelligence for the Dutch Parliament and other TA intelligence users, but they were also able to identify knowledge gaps that were not originally on the political agenda (see case study in the annex).

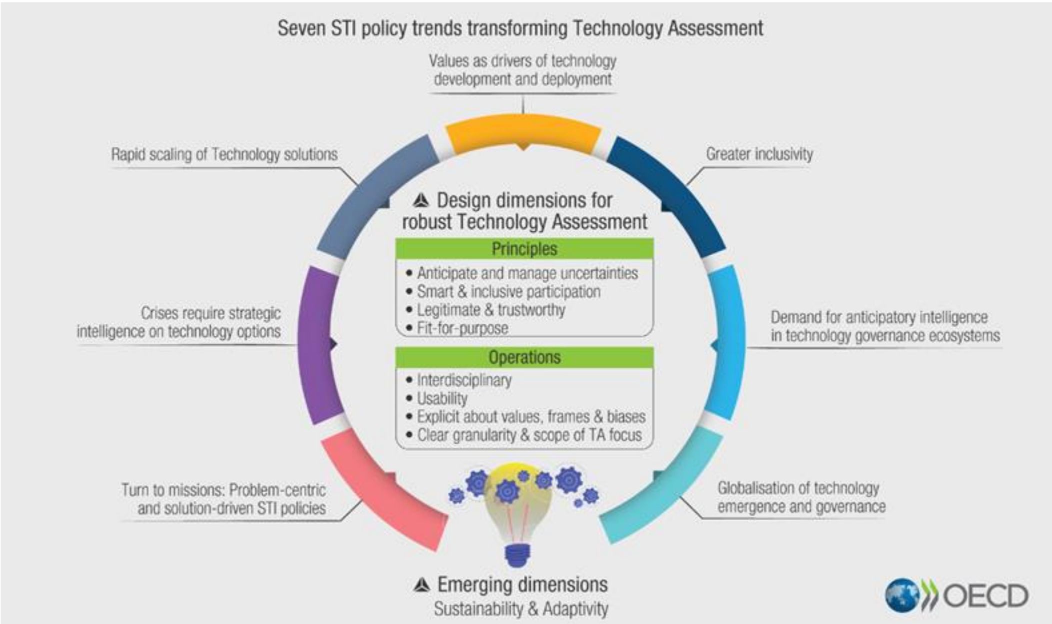
A second increasingly relevant dimension is the need for TA practitioners, and their activities, to be adaptive to the changing needs and requirements of STI governance systems. If governance systems are to keep pace with the rapid development and deployment of new and emerging technologies, they require timely and appropriate evidence. The example of NExTRAC (Box 1) shows how the mobilisation of horizon scanning to identify key technology trends is used as a means to choose a focus for its activities and also to directly connect with the decision-making needs. This means that the producers of TA intelligence must be agile and adaptive to both (a) the changing nature and maturity of a technology field and (b) the current governance and policy needs.

5 Concluding remarks: Collective intelligence for collective action?

Anticipatory technology governance is needed to harness the benefits of new and emerging technologies, and to reduce or mitigate the potential risks. It requires useful intelligence to develop strategies and policies that encourage technology for good and to avoid or mitigate potential negative consequences of new technologies. TA can help develop anticipatory capacities and generate intelligence for the governance of emerging technologies. In the context of emerging and converging technologies, this is of particular importance due to their high uncertainty in terms of development and deployment, the plethora of development pathways that are possible, the multiple actors involved and the potential high societal stakes associated with the impacts of these technologies.

TA does not look at technology in a vacuum, but technology in context (technology in industry, technology in systems, technology in daily life). The TA community is tasked to unpack current, and predict future, norms and values to generate usable strategic intelligence to inform anticipatory governance. Technology assessment capacity should seek to be distributed throughout society and draw upon various engagement processes. Participatory TA is one vehicle for this.

Figure 3. Seven STI policy trends transforming Technology Assessment



As visualised in Figure 3 above, seven trends identified in this report call for an update and even transformation of practices, tools and approaches. Further, this report has identified a (non-exhaustive) list of eight core dimensions that should be considered as TA attempts to realise its aspirations as a policy process, especially when commissioning, designing or evaluating TA activities. However, there is room for refinement and potential expansion of the eight dimensions through collaboration, coordination and/or exchange activities.

Where there are global problems, there are needs for strategic intelligence at the global scale. New collective action both international and transnational in nature might represent a fertile pathway to augment technology policy making. TA institutions around the globe are beginning to exchange strategic intelligence (in terms of TA outputs) and also expertise and capacities. For example, in the STOA case study (see annex), out of necessity from lockdown restrictions of COVID-19, STOA needed to improve the efficiency of its online stakeholder engagement methods, making the project entirely online. Through partnership with a Danish TA institution (the Danish Board of Technology) they were able to mobilise external TA process expertise and to build their own online TA capacity (see case study for more details). In the same example, STOA mobilised earlier TA outputs of the Rathenau Instituut as a direct input and foundation of its own TA exercises.

Not only are there exchanges and collaborations between TA institutions and actors, there are also crossovers and exchanges between TA actors and other producers of future-oriented strategic intelligence. For example, there is increasing overlap with the Foresight community, sharing techniques and mobilising each other's outputs within their own Foresight of TA exercises. The example of NanoTrust (Box 8 and annex section 1) shows the interplay between TA, EHS studies and risk analysis, each providing strategic intelligence to be mobilised for nanotechnology governance.

This suggests that there are real advantages to ***build international capacity*** by facilitating coordination and collaboration with other communities that are developing strategic intelligence on, and new methods for forward looking analysis of, new and emerging technologies. For example, the Foresight community, whilst placing an emphasis on exploring alternative futures, can provide key insights in public engagement through anticipatory activities. The research and innovation evaluation community are exploring new ways of anticipatory impact assessment to inform real-time evaluation of mission-oriented technology development activities (Wittmann et al. 2021). Approaching information needs for technology governance with the idea of encouraging *ecosystems of strategic intelligence* may be a productive avenue to pursue.

Is an ***international forward-looking technology assessment hub needed to exchange strategic intelligence*** products and processes for global anticipatory governance of emerging technologies? There is arguably a shortage of resources at individual TA institutions and reducing the risk of duplicating efforts is desirable. Such a hub could facilitate exchange of intelligence, foster cooperation and provide an interface between intelligence producers and policy.

Repositories and other shared resources and outputs represent low-hanging fruit.[28] However, while repositories are useful to know about past work done, they give no indication of planned work and ongoing projects. A hub that would allow for closer collaboration of TA and other future-oriented institutions, would be beneficial and enable more joint learning and best practice sharing. There is great potential in mutual learning but there is currently a lack of collaborative and best-practices.

It should be noted that, whilst we do see this trend driving pan-national and global networks as key spaces for TA practitioners to share *methods and processes*, there is no global hub that mobilizes, compares and contrasts the *strategic intelligence produced* through TA around the globe, for example, focusing on a particular technology or societal challenge. This gap could be addressed by an international organisation dedicated to the coordination and integration of strategic intelligence on pressing policy and technology governance issues.

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Endnotes

[1] This non-exhaustive list of reasons for conducting TA is adapted from the outcomes of a workshop bringing together a large number of members of the BNCT TA Steering Group in Vienna on 8-9 June 2022; workshop video accessible online at: https://www.oeaw.ac.at/en/ita/detail/news/werkzeugkiste-fuer-ta (last accessed 11.11.2022).

[2] The Office for Technology Assessment formally began in 1972 and closed in 1995.

[3] Further information on TAB online: https://www.tab-beim-bundestag.de/english/ (last accessed 11.11.2022)

[4] Currently, Princeton University maintains the OTA Legacy site, which holds the complete collection of OTA publications. For more information on the Office of Technology Assessment, see Bimber 1996. In addition, a full archive of the OTA outputs can be found at https://www.princeton.edu/~ota/.

[5] In the literature, participatory TA is often given the acronym pTA, with the "p" in lower case.

[6] In some cases, public deliberation and societal dialogue on certain technologies are legal requirements, for example the Dutch government required in 2017 that ethically sensitive legislative changes in the Dutch Embryo law would require societal dialogue (see the DNA-dialogue case study in the annex). This can also be seen in the Republic of Korea, where a revision of the Biotechnology Promotion Act has made Technology Assessment a legal requirement (see the Biotechnology Assessment in Korea case in the annex section 6).

[7] https://osp.od.nih.gov/event/upcoming-meeting-of-the-nextrac-2/ (last accessed 11.11.2022).

[8] Many facets of Constructive TA have been taken up in Europe under the banner of Responsible Research and Innovation (RRI), indeed Constructive TA is visible in the first academic publications on RRI (Robinson 2009).

[9] The agenda can be found at the following link (in Portuguese): https://www.fct.pt/agendastematicas/docs/Agenda_Industria_Manufatura_Final.pdf (last accessed on 15.11.2022).

[10] As part of the most recent update of the NNI strategic Plan, stakeholder engagement also included a virtual workshop over three days, see 2021 NNI Strategic Planning

Stakeholder Workshop: Charting the Path Forward | National Nanotechnology Initiative (last accessed 11.11.2022).

[11] The drivers and trends are the outcomes of multiple meetings of the BNCT TA Steering Group, a dedicated workshop held on 8th and 9th of June 2022 in Vienna, the presentations and discussions at the multi-stakeholder OECD conference, "Technology in and for Society" held 6-7 December 2021.desk research and informal interviews with TA practitioners and STI policy scholars.

[12] https://www.gao.gov/products/gao-21-271sp (last accessed 11.11.2022).

[13] https://www.gao.gov/products/gao-22-105841 (last accessed 11.11.2022).

[14] https://www.rathenau.nl/en/digital-governance/tackling-deepfakes-european-policy (last accessed 11.11.2022).

[15] https://www.rathenau.nl/en/digital-society/cyber-resilience-new-technology (last accessed 11.11.2022).

[16] https://www6.inrae.fr/cultiver-proteger-autrement_eng/Programme/Presentation (last accessed 11.11.2022).

[17] https://tu-freiberg.de/en/iec/evt/groups/technology-assessment-ta (last accessed 11.11.2022).

[18] Techno-centric TA can also require a value chain or systems perspective, for example, a technology assessment of nanotechnology in the food sector requires consideration of various stages of food production, processing, packaging and consumption (Robinson 2011, Robinson and Morrison 2009).

[19] https://www.openinnovation.regione.lombardia.it/it/ri-in-lombardy/regional-forum/2018-edition (last accessed 11.11.2022).

[20] https://eptanetwork.org/ (last accessed 11.11.2022).

[21] The need for recurring TA activities as a means of accompanying the development and deployment of an emerging technology was voiced in the Vienna workshop June 8th and 9th 2022 (OECD 2022b). One element of the discussion was that TA agencies must decide on developing programmes of TA around particularly important areas – the challenge is to decide which are the most important. Another element of the discussion was that a global hub, gathering strategic intelligence on a specific domain over time, might pool resources and insights from multiple TA agents and agencies.

[22] There is a danger of over emphasis on "speculative ethics" where resources are invested in far future and very speculative technological futures without a clear return on investment, whilst other nearer term issues are ignored (OECD 2014, page 24).

[23] For more information see (in French) the following link: https://www.elysee.fr/emmanuel-macron/2020/12/01/tech-for-good-plus-de-75-leaders-sengagent (Click on "Appel tech for Good" for a bilingual document listing the signatories and core values. (last accessed 11.11.2022).

[24] See Department for Digital, Culture, Media & Sport (2022) Future Tech Forum Chair's Report. Available at https://www.gov.uk/government/publications/future-tech-forum-chairs-report (last accessed 11.11.2022).

[25] White House Announces Launch of the International Grand Challenges on Democracy-Affirming Technologies for the Summit for Democracy - The White House (last accessed 11.11.2022).

[26] Further information on 2021 OECD Survey on Drivers of Trust in Public Institutions online at http://oe.cd/trust (last accessed 11.11.2022)

[27] Currently there are more than 30 members of the globalTA network (https://globalta.technology-assessment.info/) (last accessed 11.11.2022).

[28] An attempt to address duplication is the creation of repositories. An example of TA repositories are the databases of the European Parliamentary Technology Assessment (EPTA) network. EPTA consists of 25 members and is maintaining two databases (1) over 1,350 projects and (2) over 1,100 policy briefs and over 1,100 project reports. Both databases can be searched by institution, dates, names and keywords.