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List of abbreviations

AFA	ASEAN Foresight Alliance
AI	Artificial Intelligence
AIT	Austrian Institute of Technology
APEC	Asia-Pacific Economic Cooperation
APFN	Asia Pacific Futures Network
AR	Augmented Reality
ASEAN	Association of Southeast Asian Nations
ATP	Parliamentary Technical Advisory (Chile)
BMBF	Federal Ministry of Education and Research (Germany)
BTA	Business TA
CAF	Development Bank of Latin America
CEPLAN	National Centre for Strategic Planning (CEPLAN)
CFTP	Colombia's Technology Foresight Programme
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CSTF	Asia-Pacific Economic Cooperation (APEC) Centre for Technology Foresight
CGEE	Centre for Management and Strategic Studies in STI (Brazil)
CNPq	National Council for Scientific and Technological Development (Brazil)
COSTI	ASEAN Committee on Science, Technology, and Innovation
CSF	Centre for Strategic Futures (Singapore)
CSTD	United Nations Commission on Science and Technology for Development
CTA	Constructive Technology Assessment
DOST	Department of Science and Technology (the Philippines)
DTU	Technical University of Denmark
ECAST	Expert and Citizen Assessment of Science and Technology
ECLAC	United Nations Economic Commission for Latin America and the Caribbean
EIA	Environmental Impact Assessment
EIC	European Innovation Council
EISMEA	European Innovation Council and SMEs Executive Agency
EMBRAPA	Brazilian Agricultural Research Corporation
EPTA	European Parliamentary Technology Assessment Network
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
ESCWA	United Nations Economic and Social Commission for Western Asia
ESG	Environmental, Social and Governance
EU	European Union
GMOs	Genetically Modified Organisms
FINEP	Funding Authority for Studies and Projects (Brazil)
Fiocruz	Oswaldo Cruz Foundation (Brazil)
ForSTI	Foresight for Science, Technology and Innovation
FTA	Futures-Oriented Technology Analysis; Forward-Looking Technology Analysis
GAO	Government Accountability Office (USA)
GDP	Gross Domestic Product
GTAN	Global Technology Assessment Network
HEIs	Higher Education Institutions
HLCP	United Nations High-Level Committee on Programmes
HSE	Higher School of Economics (Russia)

HTA	Health Technology Assessment
ICT	Information and Communications Technology (see also IT)
IGO	International governmental organisation
INGO	International non-governmental organisation
ILO	International Labour Organization
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISSEK	Institute of Statistical Studies and Economics of Knowledge (Russia)
IT	Information Technology
ITAS	Institute for Technology Assessment and Systems Analysis (Germany)
ITU	International Telecommunication Union
JRC	Joint Research Centre (EU)
MENA	Middle East and North Africa
MIGHT	Malaysian Industry-Government Group for High Technology
NAPA	National Academy of Public Administration (USA)
NASA	National Aeronautics and Space Administration (USA)
NExTRAC	Novel and Exceptional Technology & Research Advisory Committee (USA)
NGFP	Next Generation Foresight Practitioner
NGO	Non-governmental organisation
NIH	National Institutes of Health (USA)
NIS	National Innovation System
NISTEP	National Institute for Science and Technology Policy (Japan)
OCTI	Observatory of STI (Brazil)
OPECST	Parliamentary Office for the Evaluation of Scientific and Technological Choices (France)
OECD	Organisation for Economic Cooperation and Development
OTA	Office of Technology Assessment (USA)
PIT-UN	Public Interest Technology University Network
PPP	Public-Private Partnership
pTA	Participatory Technology Assessment
PUB	Public Understanding of Biotechnology
PV	Photovoltaics
R&D	Research and Development
RRI	Responsible Research and Innovation
SDGs	Sustainable Development Goals
SENAI	Brazilian National Service for Industrial Training
SMEs	Small and Medium-sized Enterprises
SOIF	School of International Futures (UK)
STEM	Science, Technology, Engineering and Mathematics
STI	Science, Technology and Innovation
STOA	Science and Technology Options Assessment Panel (EU)
STS	Science and Technology Studies
SWOT	Strengths, Weaknesses, Opportunities and Threats
TA	Technology Assessment
TA/TF	Technology Assessment and Technology Foresight
TAB	Office of Technology Assessment at the German Bundestag
TF	Technology Foresight
TIFAC	Technology, Information, Forecasting and Assessment Council (India)
TMA-CC	Text Mining & Analysis Competence Centre (EU)
UNCTAD	United Nations Conference on Trade and Development

UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
UNTBLDC	United Nations Technology Bank for Least Developed Countries
VA	Vision Assessment
VSD	Value Sensitive Design
WHO	World Health Organization

A helpful glossary of TF-related terms is provided by the Centre of Strategic Futures (CSF) in Singapore.
See https://www.csf.gov.sg/files/media-centre/publications/csf-csc_foresight--a-glossary.pdf.

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Executive summary

This report examines the roles of Technology Assessment (TA) and Technology Foresight (TF) in contributing to policymaking for sustainable development. It outlines various ways in which the two approaches contribute to immediate and short-term political decisions (traditionally these were especially the role of TA) and longer-term strategic policies, where TF has typically played a more prominent role.

Chapter 1 discusses the meanings of the terms TA and TF. While TA and TF are distinct, they frequently overlap and are often carried out by different parts of the same organization. The report argues that the two tools are complementary. It suggests that countries should consider using them both to develop their capacity to anticipate future benefits and risks that they may face from technological changes and proactively identifies the policy actions that will be needed to harness the benefits and mitigate the risks. The report emphasizes that these are systematic activities with their own methodologies, typically involving technology forecasting approaches. These processes take time to complete and consist of several distinct stages of work.

Chapter 2 explores the roles of TA and TF in planning and policymaking, particularly in relation to the Sustainable Development Goals (SDGs). TA is typically used to support imminent technology choices, or to guide regulatory and policy considerations about emerging technologies. In contrast, TF tends to inform longer-term strategic planning. TF applications are illustrated using examples from energy production and use, though many other technological areas are also well-suited for TA. Relevant issues include AI, genomics (gene editing of human and other organisms), and nanotechnology (biological effects of nanoparticles). The wellbeing of humans and ecosystems is increasingly impacted by such technologies of wide-ranging applications. Anticipatory governance is required if policymakers and other stakeholders are not simply to be left catching up with emerging developments that have already taken hold.

Chapter 3 reviews the wide diversity of institutional models for TA and TF across countries, highlighting that approaches vary by political systems, capacities, and national priorities. Examples include Austria's decentralized network, Singapore's centralized government-led model, Brazil's multi-sectoral ecosystem, and the United States' mix of top-down and bottom-up initiatives. Countries like Russia, Malaysia, and Chile demonstrate hub-based, public-private, and parliamentary models, while others, such as the Philippines, show emerging institutionalization. Complementing national efforts, international and regional initiatives play an important role in capacity building, advancing methodologies, and promoting anticipatory governance, especially in developing countries.

Chapter 4 reviews challenges in implementing TA/TF activities and outlines a number of learning opportunities across the world. Governance gaps and institutional constraints hinder comprehensive exercises, resulting in incomplete information that undermines anticipatory intelligence. Additionally, a lack of trained personnel and robust institutional frameworks further complicates the integration of TA/TF into public administration processes. The section emphasizes the need for tailored TA/TF exercises to engage stakeholders effectively and enhance overall understanding of these approaches.

Chapter 5 presents actionable recommendations for policymakers, TA/TF practitioners, and international organizations. While a one-size-fits-all approach is completely unrealistic for countries with very different circumstances, problems, and opportunities, several general points are made.

This report highlights that while TA and TF have evolved along distinct historical trajectories, their integration offers significant value. Rather than treating them as entirely separate approaches, it is more constructive to view TA and TF as complementary tools that, when combined, can enhance policy effectiveness. A more integrated approach can support sustainability transitions by fostering inclusive dialogue, improving public and policymaker understanding of science, technology, and innovation (STI) choices, and embedding evidence into decision-making processes.

In the context of transformative innovation policies, TA and TF offer essential analytical capabilities. They can help identify obstacles within complex systems, and extend policy options by proposing forward-looking, unconventional solutions. The scope of this report extends beyond the traditional STI domain, offering insights and recommendations relevant to key sectors such as energy and public infrastructure, among others. These recommendations aim to help governments strengthen anticipatory intelligence, respond more effectively to grand challenges, and leverage technological change to diversify and modernize their economies.

1. Introduction

Technology assessment (TA) and technology foresight (TF) are two different disciplines that together provide complementary tools that can provide strategic intelligence to policymakers wishing to improve strategic planning and develop capacity for anticipatory technology governance. While complementary, they developed within largely separate communities of practice as separate disciplines. They have nevertheless converged to some degree and increasingly share some common analytical tools. TA investigates the economic, social and environmental, as well as ethical, legal, regulatory and cultural implications of developing or adopting specific technologies. It is typically applied to new or emerging technologies. There are many subcategories of TA, which means that it is not a completely uniform discipline. TF is a participatory process that explores long-term technological developments, socio-technical contexts and policy options to inform decision-making and enhance preparedness of policymakers for technological change. This report outlines their development and discusses how they have been used by countries, and how they can contribute to strategic planning and anticipatory technology governance. It also makes recommendations for how to support the wider diffusion of these tools across more countries, particularly developing countries.

This report begins with brief definitions of the two main terms, Technology Assessment (TA) and Technology Foresight (TF), based on extensive literature review. These terms are fluid, having evolved over decades and been applied to a variety of practices.[1] We clarify how the report uses them and provide examples to illustrate their application.

In this report, we are concerned only with **systematic** methods. These methods follow explicit steps to appraise the subjects of concern, and to outline their implications for human affairs and policy. While they may draw upon expert knowledge and opinion, this is very different from relying on individual expert intuition alone. Both TA and TF also tend to be **systemic**—they examine technology-related phenomena taking place in the socio-economic systems and, therefore, need to take into account the activities and capabilities of various sectors and stakeholders.

Here, the term "technologies" will be used to include specific applications of technologies. This approach is adopted to avoid repeatedly saying "technology and/or applications of technologies". Thus, "satellites" is a technology, and the application "use of satellites for remote sensing to support precision agriculture" is here also considered to be a technology. Similarly, "computer communications" and "the use of social media for sharing sustainability-related information" are both treated as technologies. Much of "classic" TA focuses on applications, and much of "classic" TF addresses broad classes of technology, but there have always been exceptions, and it is likely that the two fields have increasingly overlapped in terms of focus, time horizons, and other aspects. We illustrate both concepts below, with examples of each.

1.1 Definitions and Examples: Technology Assessment

Background and motivation

Legislative efforts to limit pollution and threats to human health posed by technologies date back centuries. However, since the early 1960s, public concern about adverse effects of scientific and technical innovations has significantly intensified, especially in industrialized nations. Climate change, serious accidents in industrial facilities, widespread air and water pollution, and the discovery of negative health effects of materials such as asbestos have all highlighted the negative impacts of technology (Goldberg & Luce, 2009; HEI *et al*., 2024; UN-Water & UNESCO, 2023). Additionally, social and cultural 'side effects', such as disruptions to the labour market due to automation, have gained increasing recognition (Acemoglu & Restrepo, 2019; Balsmeier & Woerter, 2019; Susskind, 2020). The global nature of adverse effects has become increasingly visible, manifesting in critical issues such as climate change, plastic and microplastic pollution, and loss of biodiversity (IPCC *et al*., 2023). The 'Limits to Growth' scenarios in the 1970s had already attracted much public attention, highlighting the resource constraints tied to technological and economic expansion (Meadows & Randers, 2012).

The recognition of the unintended and often undesirable consequences of technology and innovation highlighted the need for anticipatory governance to understand the full spectrum of these impacts (Dufva & Rekola, 2023). This awareness also generated a demand for expert guidance, including actionable strategies for policymakers and society at large.[2] The combination of these factors was an essential reason for the emergence

1 Use of "Technology Assessment" in the titles of publications goes back to at least 1967, when Science carried a piece with that title. "Technology Foresight", in contrast, first appears in titles only in the early 1990s.

2 Contribution from the Government of Poland.

of **Technology Assessment (TA)**. Since the 1970s, various regulatory and scientific approaches have been developed and implemented to help prevent or manage problematic effects of technology change, with TA playing a central role.

TA is a challenge-driven, problem-oriented field that employs its own set of methods, combining scientific exploration of issues with the practical application of the knowledge generated, such as providing scientific advice for policymaking (Grunwald, 2018). As an interdisciplinary research field, TA investigates possible, or probable (plausible) consequences of technology and innovation in a broad sense. It generally looks for potential benefits and gains while also examining unintended side effects.

These consequences stem not from technology alone, but from the ways it is applied through human actions. Therefore, TA must consider the complex relationships between technology and innovation on one side, and human behaviour, regulation, and political and economic conditions on the other.[3]

Beyond conducting systematic research, TA aims to provide knowledge and orientation for better-informed and well-reflected decisions for shaping and responsibly managing the outcomes and consequences of future technological advances. TA seeks to offer *knowledge for action*, for example, by engaging at the science-policy interface and offering well-grounded policy advice to support decision-making at various levels. Thereby, TA aims to 'make a difference' in addressing real-world issues. This impact may include providing usable knowledge for engineers in the design process of new technologies, offering policy advice for political debate and decision-making, raising public awareness, or contributing to the wide range of actions involved in sustainability transitions.

History and current status

TA originated over fifty years ago in the political context of the United States Congress. The Office of Technology Assessment (OTA) was established in 1972 to support Congressional deliberations by analyzing unintended side effects of technological progress and weighing associated risks and opportunities. The OTA operated for over two decades, publishing over 750 full assessments, background papers, technical memoranda, case studies, and workshop proceedings on a wide range of foresight topics.[4]

The emergence of TA in the United States was observed by other Western countries, and TA was adopted in technology management and planning across an increasing number of OECD member countries. The first European offices of parliamentary TA were founded in the 1980s (e.g., Denmark, the Netherlands), and the number of parliamentary TA units has since grown steadily, expanding globally and becoming institutionalized, as exemplified in Germany (Box 1). Currently, the European Parliamentary Technology Assessment Network (EPTA) comprises more than twenty members from Europe, as well as from the United States, Japan, Chile, Argentina, and the Republic of Korea.[5] While their role as a support to parliaments is a widely used model, many countries also feature TA at the executive level, located within ministries, departments, and agencies.

TA provides knowledge for responsibly managing outcomes of future technological advances

3 Technology Assessment is distinct from technology awareness. While technology awareness refers to the capacity to stay informed about technological trends and their potential impacts, Technology Assessment is a systematic approach that uses scientific methods to investigate the conditions under which technologies operate, as well as their potential consequences, to support informed societal evaluation.

4 Contribution from the Government of the United States of America.

5 For more information on the European Parliamentary Technology Assessment (EPTA) network, visit https://www.eptanetwork.org/. Additionally, the European Parliament has its own Panel for Science and Technology Options Assessment (STOA), which can be explored at: https://www.europarl.europa.eu/stoa/en/home/highlights.

TA contributes usable knowledge for technology design, informs policy decisions and raises public awareness

Following TA developments in the 1980s and 1990s, current TA activities can be classified into three major fields:

(1) TA as systematic, evidence-based policy advice: In this field, the objective of TA is to support policymakers by providing them with anticipatory information, ethical reflection, and alternative strategies on how to proceed in their respective fields. This may happen at different levels of governance. Parliamentary TA is a sub-category of policy-advising TA, based on the premise that parliaments play a crucial—or at least a relevant—role in technology governance and science policy.

(2) TA as a contribution to public dialogue: The public may be affected by technological change and have views on these changes and on ethical issues arising in scientific research. Public views and actions based on them may play different roles at different stages in technology development, but the general public often lacks adequate knowledge of STI. Normative ideas of deliberative democracy derive from recognition that those involved in democratic decision-making need to have a sufficient knowledge base. Thus, many practitioners will argue that TA should engage stakeholders, citizens and other people affected by change in assessment processes. By fostering public participation, TA helps ensure that ethical and societal considerations are more thoroughly addressed in the development and use of technology.

Box 1.
Office of Technology Assessment (TAB) at the German Bundestag

Germany is a country where both TA and TF are well-established, with TAB, the Office of Technology Assessment at the German Bundestag, being established in 1990 as an independent scientific institution to advise the Parliament and Parliamentary committees on STI issues.[6] Known as an "honest broker" free from party-political bias, TAB has several studies due for completion in 2024, including the societal impact of working from home, the legal and societal challenges of deepfakes, the environmental impact of offshore wind farms, among others.[7] Ideas for topics to consider are presented by committees and parliamentary groups of the German Bundestag, TAB assesses the scientific feasibility, objectives, contents, and methods of a possible project, and committee meetings decide on the agenda of work.

It is often challenging to trace the impact of a TA project, though TAB reports that their studies commonly feature in Parliamentary and other debates in Germany, with some results and recommendations adopted by German ministries. Grunwald (2018) sees three different ways in which Parliamentary TA is institutionalised: (1) a dedicated Parliamentary committee that invites experts to testify, organises workshops and conferences to deliberate on and debate issues and policies; (2) a Parliamentary office or unit that conducts or manages contracted-out studies at the request of Parliament; (3) an independent institute that operates at a distance from Parliament (which is its main client), and which often aims to stimulate public debate as well as to inform policymakers directly.

TAB is working to diversify its project portfolio by moving away from lengthy two-year studies (with results presented only after this period), and becoming more closely aligned with current technological developments, swiftly translating insights into policy recommendations for the German Parliament. To address this need, new formats for providing rapid advice have been established. This represents a significant shift from the approaches practiced 30 years ago.

6 Contribution from the Government of Germany.

7 The TAB website indicates a management team of 5 people, with 7 researchers, and collaboration with at least two other German research organisations.

(3) TA for shaping technology: The shaping of technology is a social process and recognition of this is reflected in the emergence of such TA approaches as *Constructive TA* and *Value Sensitive Design (VSD)*. TA in this respect aims at enriching engineering and other design processes by taking social expectations and values into account, which may involve drawing on insights from social science or from engaging stakeholders in examining ways in which innovations may be realized.
In recent decades, political and societal requirements, particularly those related to achieving sustainability and addressing climate change, have significantly shaped TA. These requirements are driven by global agreements, such as the Paris Agreement, and by the increasing urgency from both governments and civil society to develop technologies that meet the SDGs.

These different strands of TA all encounter a set of diverse and heterogeneous challenges that have risen to the fore in recent decades. Among these are the rapid pace of digital transformation, which has revolutionized every aspect of societies and economies (Plekhanov *et al*., 2023), the diagnosis of the Anthropocene[8] (Crutzen, 2002; Crutzen & Stoermer, 2000; Lewis & Maslin, 2015), highlighting humanity's profound impact on the planet, and the ongoing tension between technocracy and democracy (Schaake, 2024), which raises questions about the governance of technological advancements. Additionally, the increasing dependency on critical infrastructures has underscored the importance of resilience and security (Edler *et al*., 2023), while economic and cultural globalization has brought about both opportunities and challenges for equity and cultural integrity (Bu *et al*., 2021; Jensen *et al*., 2011).

In response to these complex and interrelated challenges, TA has established a variety of interdisciplinary and transdisciplinary practices and methodologies. These approaches span research, policy advice, public engagement, and knowledge transfer, enabling TA to more effectively navigate and contribute to the diverse needs of modern societies.

Conceptual Dimensions

The challenges motivating TA and its fields of practice are too broad, and in several ways too heterogeneous, to allow for the creation of a clear and specific definition of TA which can be universally accepted. However, it is possible to derive an overarching *cognitive interest* of TA which consistently guides its activities across all fields.

At its core, TA is about *supporting, strengthening and enhancing reflexivity in all epistemic and social fields of reasoning and decision-making that bear on shaping scientific and technological advances, on the usage of the outcomes of such advances, and on dealing with the consequences to present and future society*.

This cognitive interest is reflected in TA's key functions: supporting democratic and evidence-based reasoning through policy advice, strengthening public debate by providing knowledge and acknowledging uncertainties, and contributing to the design and development of technology. Instead of following 'wait and see' approaches, often characterized by biased techno-optimism or suspicious and fatalist techno-pessimism, TA supports research-based, societal learning processes that address technological advancements and their outcomes in a reflexive manner.

Reflexivity involves the ability of individuals or groups to examine their own emotions, reactions, and motives related to a specific topic, and to recognize how these factors influence their perceptions, use of evidence, and the judgments that guide their actions regarding that topic.

TA fosters public participation, ensuring ethical and societal considerations in technology development and use

TA enhances reflexivity and applies structured approaches to managing the complexity of technologies

8 The term "Anthropocene" refers to a proposed geological epoch that highlights the significant and lasting impact of human activities on the Earth's geology and ecosystems.

TA includes parliamentary, participatory, constructive, hermeneutic, value-sensitive, demand-oriented, real-time, health, and business approaches

This is rather an abstract notion and can be made more tangible by considering three conceptual dimensions:

- *Anticipation*: '*enhancing reflexivity*' means taking the perspective of *shaping* the future seriously, and not simply subscribing to technological determinism, in which the direction of technological change is seen as a given to which societies must adapt. This approach means considering a broader range of future developments and possible consequences of technology, thinking about alternatives, and keeping options open rather than prematurely settling on a single path. Due to its anticipatory and prospective view, there is considerable overlap with TF, particularly concerning methodology (this is elaborated further in the subsequent sections).
- *Inclusion*: TA enhances reflexivity by addressing a large variety of perspectives and involves a broader range of actors such as stakeholders and citizens with their knowledge, values and interests, building on the rich tradition of participatory TA (see below) rooted in normative ideas of deliberative democracy.
- *Complexity management*: In TA projects, decisions about relevance must constantly be made to manage the complexity of the issues involved. For example, it will be necessary to decide which of a huge range of possible futures should be considered. Enhancing reflexivity means critically scrutinizing the numerous judgments on relevance that are inevitably part of this process, including setting system boundaries, deciding which actors to include or exclude, and making priority decisions.

TA approaches and subcategories

In the more than 50 years of TA's existence, several approaches and concepts have been proposed and—partially—also put into practice. The following list aims to give a brief overview about relevant TA approaches. It does not claim completeness, and other classifications have been proposed (e.g., Musango & Ouma-Mugabe, 2024).

Parliamentary TA: TA emerged at the parliamentary level with the foundation of the USA's Office of Technology Assessment (OTA) in 1972. Many other countries adopted this model in subsequent years, with the European Parliament also having its own TA unit. This type of TA informs members and committees of parliaments about trends in science and technology, opportunities and risks, and options and needs for political intervention, e.g., for regulating or promoting specific developments (Weber *et al*., 2019).

Participatory TA: This TA approach emerged in the 1980s, with the aim of democratizing technology by bringing relevant decisions into more deliberative democratic processes. It engages stakeholders, citizens, civil society organizations, and people affected into the assessment processes.[9] In subsequent decades, its inclusive nature has become a constitutive part of TA in general, though the extent of the range of stakeholders, and the degree of their engagement, varies considerably.

Constructive TA (CTA): Instead of exploring possible or plausible consequences of new technology, CTA asks how new technologies can be shaped in line with social values and stakeholder interests. This approach is more focused on realizing intended and *desirable* consequences, than being dedicated to considering possible unintended consequences.

9 In the context of NASA's Asteroid Initiative, pTA was exemplified through a collaboration with the Expert and Citizen Assessment of Science and Technology (ECAST). This initiative engaged diverse public participants in structured forums to discuss asteroid detection and mitigation strategies, thereby providing valuable insights for decision-making. For more information, visit https://issues.org/nasa-asteroid-initative-pta-farooque-kessler/.

Hermeneutic TA: The uncertainty of prospective knowledge and sometimes its complete absence motivates one to consider statements about the future from a different angle. Here, one can ask what such statements tell us about the present situation. Ideas about future possibilities are regarded as texts in the present, whose authors and disseminators with values, diagnoses, and interests, which often is a valuable source of information for policymakers. Associated with this, *Vision Assessment (VA)* considers the intentions involved in articulating specific accounts of the future. For example, are they intended to motivate funders or attract venture capital, or perhaps to undermine one potential course of action in order to build support for another? VA looks behind the façade of visionary rhetoric and uncovers the present interests and values involved.

Value Sensitive Design (VSD): This more philosophical approach supports integrating values into the design of new technology, and has been applied mainly in relation to advancements in digital technologies. It is close to the "ethics by design" or "privacy by design" approach (Donia & Shaw, 2021) and aims to implement values so strictly that later misuse could be largely excluded.

Demand-oriented TA: Criticisms of TA have repeatedly argued that it looks at the consequences of technological advances that it takes for granted, implicitly following a "technology push" approach that ignores possible alternatives. This approach suggests first, asking consumers, users, and stakeholders for their needs and then to start designing the relevant technology, rather than assuming that the innovators know best. This TA starts, therefore, with a "*needs assessment*".

Real-time TA: This approach is more of an emerging idea than an elaborated operational approach but has received interest since accelerating technological advance is seen to leave decreasing time for careful analysis with which to inform decision-making. More rapid analysis is needed to correspond to areas of rapid technological change, and TA practitioners are exploring new methods, often based on using technological advancements for large scale data analysis, for internet-based online consultations and information gathering. The hope is to shorten the time required for evidence-based advice to parliaments and other stakeholders.

Health TA (HTA) is its own subcategory of TA, which is undertaken by many government agencies and consultants in national health systems. It looks at direct health effects, effective and efficient health measures, safety and risks, and at the potential costs of health technologies compared to other medical drugs or treatments. HTA is largely separated from the wider TA community. In fact, it has formed its own community with specialist conferences and journals. Rather similar tendencies are apparent in areas such as the Environmental Impact Assessments. However, there are points of contact between these two fields. For example, general TA may be called upon to examine ethical issues in biomedical research, the longer-term implications of new medical technologies, and other matters that go beyond comparing costs and benefits of specific treatments.

Business TA (BTA) refers to decision-making approaches employed by private businesses and in some government bodies and public services, mainly with reference to the choice between specific technological options to be applied within business processes. It asks which options offer the best return on investment.[10] BTA involves assessing how technologies align with the organization's strategic goals, such as their potential to enhance efficiency, competitiveness, and innovation. Regulatory or consumer pressures may

Participatory TA democratizes technology decisions by engaging with stakeholders including citizens and civil society

TA aims to provide **faster evidence-based advice to policymakers**

10 Also known as business, or strategic TA, this activity is addressed in a wide range of technology management and technology strategy journals and organizations.

lead to sustainability issues being built into such BTAs, and investors have increasingly examined the Environment, Social, Governance (ESG) ratings of businesses.

TA in transition

TA is evolving into a **foresight-integrated approach and can enable longer-term analysis**

In this report, TA refers to the systematic appraisal of the consequences of technology development and, particularly, adoption. It examines specific technologies and their social, economic, and/or environmental implications. While TA is typically applied to new or emerging technologies, it can also be used to assess existing technologies or those that are the focus of technology forecasting, including product development timelines and diffusion dynamics.

"Classic" TA typically focuses on the short-term implications of specific technologies or their applications, including unintended consequences (Musango & Ouma-Mugabe, 2024). However, over the past 20 years, with the emergence of new technologies like nanotechnology and synthetic biology, TA has evolved. The Vision[11] Assessment approach within TA, for example, specifically addresses possible long-term issues (Grin & Grunwald, 2000; Schneider *et al*., 2023).

TA has seen limited use in Africa **outside of environmental impact assessments and health TA**

Technological consequences can span issues such as sustainability, competitiveness, employment, and broader societal impacts. Assessments often reveal uneven effects across different age groups, genders, regions, or social groups. The related term, **Impact Assessment** is most often reserved for examination of the environmental or economic consequences of projects, though organizations like the International Labour Organisation (ILO) and UN Women are working to broaden this scope to include gender and job equality issues.

For example, though TA is still in its early stages in most African countries, Environmental Impact Assessments (EIAs) and health-related TAs stand out as areas where TA has gained some traction in Africa. EIAs, usually led by national environmental agencies, concentrate on assessing the environmental impacts of technologies and projects. However, these processes often occur with limited integration into STI policy frameworks, which restricts their broader impact on policymaking.

TA can be employed to focus on specific technologies, analyzing their short-term consequences (typically within a three to five-year horizon) to generate actionable policy options. Additionally, TA can extend its focus to socio-technical factors, examining the broader context of technological change and the potential challenges these technologies might induce. The goal is to thoroughly analyze these issues from an ecosystem perspective, where technology is part of a value chain, and to develop viable alternatives for the future.[12] This is where foresight methods become crucial. Therefore, a well-rounded TA should incorporate foresight methods, as it is essential to consider long-term outcomes and consequences.

In the 1970s and 1980s, TA and TF evolved independently in OECD countries (Coates *et al*., 2001). However, by the 1990s, foresight, particularly scenario development, became a more integrated component of a broader, fit-for-purpose TA framework. This convergence gained momentum in the early 2000s with the rise of nanotechnology across industrialized nations, exemplified by approaches like anticipatory governance and responsible innovation (Fisher, 2019).

In the USA, this evolution influenced a 2019 NAPA study,[13] which recommended

11 Vision in TA can be defined as a forward-looking perspective that integrates expectations about the future potential of technologies, guiding decision-making processes and influencing stakeholders' actions.

12 Contribution from the Organisation for Economic Cooperation and Development (OECD).

13 For more information, see the 2019 Report by a Panel of the National Academy of Public Administration 'Science and Technology Policy Assessment: A Congressionally Directed Review, available at https://napawash.org/uploads/Academy_Studies/NAPA_FinalReport_forCRS_110119.pdf.

the revival of the Office of Technology Assessment (OTA) and proposed creating a new office to incorporate foresight into the Government Accountability Office's (GAO) Science, Technology Assessment, and Analytics (STAA) unit, which had already surpassed the size of the original OTA and become a major centre of TA activities. Despite the growing convergence between TA and foresight, the GAO offices responsible for these areas tend to function somewhat independently.

The rapid pace of technological advancement in some areas and the complex implications of emerging technologies necessitate a more integrated approach. In practice, institutions dedicated to TA have increasingly integrated foresight methods over the years. This integration is seen in the institutionalization of TA offices and organizations, which have adopted many classic foresight techniques. For instance, organizations like the EPTA and various national TA offices have incorporated scenario planning, Delphi methods, and horizon-scanning, traditionally associated with TF.

It is more productive to view TA and TF as complementary rather than as entirely separate approaches. Both play crucial roles in technology governance, and their integration can significantly enhance the effectiveness of both TA and TF exercises. Recent developments in technologies such as Artificial Intelligence (AI), gene editing technology[14] and quantum technology[15] highlight the importance of closely connecting TA and TF. TA addresses immediate and near-term issues, while TF provides a framework for anticipating longer-term possibilities. Together, they help to proactively anticipate and prepare for emerging and future technological developments.

1.2 Definitions and Examples: Technology Foresight

Technology Foresight (TF) involves systematic appraisals of technology futures, usually drawing upon, but not being restricted to technology forecasting. TF usually considers a longer time frame than is conventional for policymaking, often exceeding ten years. The primary aim of "classic" TF is generally to inform and help shape decisions about what capabilities are needed to create or implement prospective technologies.[16]

TF usually engages multiple stakeholders alongside experts knowledgeable about a range of technologies and their applications.[17] It draws upon the knowledge from both sources to examine opportunities for policies and strategies that maximize economic and social benefits, while considering costs, including environmental damage in many recent exercises. In addition to gathering knowledge from multiple sources, TF gains political legitimacy from involving a range of interest groups and going beyond the "usual suspects" who traditionally provided advice on STI policies.

It is more productive to view TA and TF as complementary rather than separate approaches

TF systematically explores long-term technological developments, socio-technical contexts and policy options, informing decision-making

14 See TA project on gene drives research and biotechnology by the U.S. National Institutes of Health (NIH) Novel and Exceptional Technology & Research Advisory Committee (NExTRAC), available at https://osp.od.nih.gov/nextrac-gene-drives-research-emerging-biotechnology-framework/.

15 See TF project by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia titled "Understanding Quantum Readiness Across Australian Industry Sectors" (July 2023-June 2025), which evaluates the feasibility of integrating quantum technologies into Australian industries, available at https://research.csiro.au/ri/understanding-quantum-readiness-across-australian-industry-sectors/.

16 Beyond technological implications, foresight methods can be applied broadly across various sectors and fields, making the term "**strategic foresight**" very common. In policymaking, strategic foresight enables governments to anticipate long-term societal, geopolitical and economic shifts, thereby enhancing resilience and responsiveness to emerging challenges. In business, strategic foresight (also referred to as **corporate foresight**) assists organizations in recognizing trends, identifying business opportunities and risks early, and adapting corporate strategies to maintain competitiveness in dynamic environments.

17 Contribution from the United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP).

ForSTI treats technology as **one part of a wider socio-technical system**

TF can range from relatively focused assessments of future prospects for a specific category of technology—such as identifying actions needed to maximize opportunities in that area—to broader, wide-spectrum explorations across multiple technology fields. These broader assessments might ask which fields warrant particular attention, prioritization, or specialization. The scope of concern can vary as well, from a specific industrial sector or policy area to a much wider set of sectors. Additionally, the knowledge exchange that the process involves can help foster better linkages in innovation systems and across different policy communities, as various policies may intersect and require coordination.

The term Foresight for Science, Technology and Innovation (**ForSTI**) includes "classic" TF, but treats technology as one part of a wider socio-technical system. On the one hand, technology development may require new scientific knowledge, necessitating basic research in addition to applied R&D. On the other hand, the effective uptake and use of technological opportunities requires enabling contexts to facilitate innovation. This may involve addressing legitimate concerns that can underlie opposition to certain technology developments.[18]

While much ForSTI follows "classic" TF practice and begins by examining technological opportunities, exercises are increasingly oriented around major social or environmental problems. In these cases, where sustainable development issues are increasingly prominent, the aim is to identify measures that can contribute to addressing such challenges, while considering evolving socio-political circumstances. The emphasis will often be on planning for R&D, technology innovation and adoption, and the development of human resources for STI.

Although TF (and ForSTI) may be commissioned by various clients, many key exercises undertaken have been at the behest of government ministries or departments concerned with STI, particularly those overseeing R&D funding and skills development. Ministries with environmental and related mandates often undertake these activities too. In some countries, TF centres are embedded in national planning bodies. In Peru, for instance, the National Centre for Strategic Planning (CEPLAN) manages the National Foresight Observatory,[19] which annually analyzes global and national technology trends to inform policy and planning within the National Strategic Planning System (SINAPLAN).[20]

There are many examples of the use of TF to inform decision-making. Japan notably pioneered large-scale application of TF to inform its STI funding priorities. Since 1971, large-scale science and technology foresight surveys have been conducted roughly every five years in Japan. The National Institute of Science and Technology Policy (NISTEP) has been implementing these surveys since the fifth survey (1992).[21] The use of Delphi and other TF methods by Japan inspired much of the practice adopted (and adapted) across the world at the end of the 20th century (Georghiou, 2008; Miles, 2010).[22] The series of Japanese exercises were influential on European TF programmes in the late 1980s and 1990s. These programmes were used by several countries to reinvigorate their

18 One rationale for adoption of the ForSTI terminology is that as the term "Foresight" became very popular. It has often been appropriated to apply to more limited types of horizon-scanning and forecasting activity.

19 Contribution from the Government of Peru.

20 In 2023, CEPLAN published a foresight guidebook, including methods like technology roadmaps, Delphi analysis, structural analysis, scenario planning, backcasting and SMIC. The guidebook can be accessed via the following link https://www.gob.pe/institucion/ceplan/informes-publicaciones/6078850-guia-de-prospectiva-para-las-politicas-y-planes-del-sinaplan-actualizada-2024.

21 Contribution from the Government of Japan.

22 Japan's main institution implementing TF is NISTEP. For the impact of its approach see Miles (2010). Georghiou *et al*. (2008) provide accounts of TF worldwide early in the present century.

Box 2.
Example of EU TF initiative – ANTICIPINNOV project

The ANTICIPINNOV project, designed for the European Innovation Council (EIC) and implemented in collaboration with the European Innovation Council and SMEs Executive Agency (EISMEA) and the Joint Research Centre (JRC), aims to enhance the EIC's strategic intelligence capabilities by developing and applying a foresight approach. This project involves horizon-scanning to identify and analyze emerging scientific and technological developments, or weak signals, around specific technological portfolios, with the goal of highlighting investment opportunities in emerging technologies and breakthrough innovations.

Signal detection was carried out using both quantitative and qualitative analyses. Quantitative methods involved data analysis from databases like PATSTAT, a global patent database, and SCOPUS, a bibliographic database of scientific literature. This analysis assumed that sudden increases in scientific papers or patents could indicate early-stage technology development. Qualitative signal detection involved experts, who were tasked with identifying significant signals based on defined criteria, ensuring that each signal represented clear novelty and was traceable to its sources. This information was cross-checked against a literature review on technology and innovation trends, with additional content added as necessary. The filtered signals were compiled as reference material and provided to workshop participants for preparation.

At the end of each workshop, a "Futures Triangle" activity was conducted (e.g., Fergnani, 2019), where experts discussed the trends and issues shaping the development within each PM portfolio. These discussions categorized issues into drivers, enablers, and barriers, providing a framework for stakeholders to consider the various factors that could influence future developments in each portfolio.

STI policies. For example, in Portugal, foresight methods were introduced with the Science Law in 1986.[23]

The experience of Japan and later the USA led the EU[24] to use TF exercises to shape its multi-year research and innovation "Horizon Europe" funding programmes (Box 2). The programmes allocate billions of euros to research areas identified as critical for Europe's future competitiveness and its ability to address societal challenges (Weber *et al*., 2023). Traditionally, TF exercises have served to map out a broad spectrum of STI activities, guiding decisions on public investments in R&D, education, and related areas. Some developing countries, typically facing small STI budgets, have also recently adopted TF or ForSTI exercises to provide a basis for establishing national priorities for research, technology and innovation in environments of high resource scarcity.

One of the key reasons for employing TF is its capacity to enhance preparedness for future uncertainties (Weber *et al*., 2015). Its significance lies in its ability to empower policymakers to be aware of, consider and focus on, the complex dimensions involved, the various scenarios that may develop, and the potential opportunities and costs of alternative outcomes. By exploring and understanding multiple future possibilities and their interactions, TF *challenges* existing visions of the future and offers alternative perspectives, helping to broaden the scope of strategic thinking (Lang & Ramírez, 2023).

TF is conducted by various entities, including large companies that may have dedicated in-house teams focused on

> **TF challenges existing visions of the future** and offers alternative perspectives, broadening strategic thinking's scope

23 Contribution from the Government of Portugal.

24 At the EU level, further policy learning activities have been initiated, including the Mutual Learning Exercise on Foresight and the current "Eye of Europe" network, which enhances foresight capabilities and promotes collaborative approaches within EU member states.

TA and TF increasingly converge, both responding to transformative technologies through systemic, multidisciplinary, policy-relevant approaches

analyzing technological developments (Webb, 2024).[25] These teams examine competitors' strategies and objectives, shifts in supply chains or markets that may influence the supply and demand for specific components and designs, as well as potential regulatory trends that could affect their operations (Fergnani, 2022; Rohrbeck *et al*., 2015). There are many consultancy firms active in providing relevant knowledge and analysis in these fields, and some of these will support governmental TF activities. In many countries, there are well-established groups in Higher Education Institutions (HEIs) that conduct relevant studies and can provide expertise. These institutions are typically more motivated to explain their tools and techniques than are commercial organizations.

1.3 Contrasting Technology Assessment and Foresight

Both TA and TF are encompassed by another term, that was popularized by a number of European initiatives in the early years of this century. This is Future-Oriented Technology Analysis (FTA) which also covers more limited activities such as technology forecasting.[26] This portfolio terminology is frequently encountered in the titles of numerous publications and conferences, though it appears to remain most popular in Europe.[27] Here we will use TA/TF to cover the ensemble of approaches. Table 1 sets out to contrast "classic" forms of TA and TF, but it must be recognized that there is much overlap between the two practices. This is hardly surprising, since both are concerned with new and emerging technologies within their socio-economic contexts.

Technological change is inherently a social process involving producers, users, communities and workers

Indeed, the two approaches can be traced back to the same initial bodies of work in the decades prior to the Second World War, especially in the USA. They became more evidently separated in the postwar period, when they tended to be shaped for different policy actors and the issues that these were concerned with. Different sorts of concern about technology became more prominent in policymaking over this period (Table 2).

Both activities encountered the need to address interactions between different aspects of economy and society when it comes to technological change. There are producers, supply chains, and markets; designers and users of new products and processes; and stakeholders such as the communities where production takes place, along with various categories of workers involved in production and distribution. Technological change is inherently a social process, but depending on the purpose, one may focus on different aspects of this process.

One set of outcomes of the change process is examined in technological forecasting, which both TA and TF typically draw upon whether this be more short or long-term focused. TA may be more concerned with forecasts of technology uptake, while trends in technology performance may feature more in TF but there are many exceptions to this. The knowledge required to assess the immediate impacts of near-term developments is likely to differ significantly from that needed to consider the longer-term implications of technological change.

25 For more information, read the article on horizon planning for boards, available at https://www.icaew.com/technical/corporate-governance/new-boardroom-agenda/scenario-planning-guide-for-boards.

26 For instance, The Parliamentary Office for the Evaluation of Scientific and Technological Choices (OPECST) in France is a key institution in France for managing FTA, conducting investigations into the impacts of science and technology, and offering policy recommendations to the French Parliament.

27 FTA is sometimes replaced by Technology Futures Analysis (TFA) which arguably places more emphasis on the technology than the futures-orientation.

Table 1
Contrasting "classic" TA and TF

Typical Characteristics	Technology Assessment (TA)	Technology Foresight (TF)
Focus	Consequences of technology development and adoption	Opportunities for technology development and adoption
Time Horizon	Often shorter to medium term (years)	Longer-term vision (decades), though related to policies in immediate future
Thematic orientation	Focuses on specific technologies or applications. May consider issues around major emerging fields	Examines broader technology fields, potentially covering the entire STI landscape relevant to a country or specific challenge. Often focuses on innovation systems, with activities aimed at reshaping these systems
Fields of expertise often employed	Multidisciplinary, including science and technology studies (STS), policy analysis, and sociology	Multidisciplinary, including Innovation studies, design, and management studies
Methods employed	Workshops, public surveys, stakeholder interviews, technology trend and impact analyses, design tools. May involve a wide range of stakeholders including affected communities and employees	Workshops (including scenario analysis), Delphi, SWOT analysis. Wide participation from industry experts, academics, policymakers, and some representation of stakeholder groups
Use of technology forecasting data and models	Focuses on the diffusion and implications of widespread technology adoption, and sometimes on "reinvention" (unanticipated uses of new products)	Focuses on product development, including gaps and obstacles in commercialization, product cycle issues. The Delphi method is often used to gather expert insights on potential technological developments
Organisations commissioning work	Main clients often include national parliaments or governments. In areas of public concern, work may be commissioned by professional bodies, learned societies, or membership organizations (e.g., trade unions, environmental groups)	Main clients often include ministries or government agencies involved in STI, such as those responsible for R&D funding
Policy Outputs	Informing near-term policies related to introduction, use, and regulation of new technologies	Informing strategic planning in STI policy and technology development across various policy areas

Note: The differences between TA and TF listed above are somewhat exaggerated. Furthermore, it can be argued that, over time, these activities have become more similar in many of the features mentioned. There are also overlaps between one or both of these broad activities and several other fields, such as risk management, preparedness planning, and resilience, as well as climate change and ecosystem modelling, Environmental Impact Assessment, and related domains. Each of these areas has its own communities and bodies of literature.

In the longer-term, social, economic, and environmental conditions may have changed considerably, and the forms taken by technology design and uptake are more uncertain. Thus, while both TA and TF seek to develop systemic as well as systematic and multidisciplinary approaches, they often employ different types of knowledge, expertise, and methodology. Arguably, there is some convergence between the two approaches in more recent years.

Two factors may underpin this. First, the emergence of various classes of technologies with broad applications that have the potential to significantly transform multiple economic sectors and social practices. Second, the growing focus on addressing 'grand challenges' such as climate change.

Table 2
Evolution of TA and TF

Rough Time Period	Technology Assessment (TA)	Technology Foresight (TF)	Historical Context
Up to 1920s	Terminology yet to be introduced; discussions relied on 'genius forecasting' by experts.	Similar reliance on individual experts, with no formal methodology.	Pre-modern TA/TF methods focused on expert-driven insights.
1920s-1930s (Era of the Great Depression)	Ogburn W.F. (1923) analyzed innovation and socio-technical change. In 1937, the U.S. report 'Technological Trends and National Policy' marked the first modern TA, focusing on economic and employment impacts of technology.	Ogburn W.F. (1923) and Gilfillan S. C. (1935) also contributed to early technology forecasting, using quantitative measures. Wells H.G. (1932) called for 'Professors of Foresight,' but framed in terms of TA (impacts of new technologies).	Emergence of formal analysis of technology impacts and early forecasting efforts.
1940s-1960s (World War II, Cold War, postwar boom, space race, decolonization)	Discussions on the implications of nuclear weapons. The Pugwash Conferences on Science and World Affairs (1957) highlighted global security risks, especially nuclear threats, pushing for international regulation.	Significant development of technology forecasting and futures research, mainly through U.S. military programs. NASA and some corporations adopted foresight tools for planning.	Military-driven TF methods; global security concerns sparked international dialogue on technology risks.
1960s-1980s (Vietnam War, cultural and political turbulence, rise of Newly Industrialized Countries in Asia)	Rising concern over technology risks (nuclear power, pesticides, employment impacts). Toffler's 'Future Shock' (1971) spurred interest in anticipatory governance. The U.S. Office of Technology Assessment (1972) provided policymakers with advice on technological changes, and similar initiatives spread globally.	Increased focus on global population growth and resource use, exemplified by 'Limits to Growth' (Meadows *et al.*, 1972). Japan's NISTEP adapted the Delphi method for national forecasting to move from 'catch-up' to technological leadership.	Increased focus on TA and TF, with both addressing environmental risks and global challenges.
1980s-2000s (Slowing postwar boom, collapse of USSR, rise of microelectronics, dot-com bubble, growing climate change consensus)	Social movements protested environmental risks from industrial and agricultural technologies. Impact assessments became more common, though unevenly applied. TA increasingly addressed employment concerns linked to automation.	'Foresight' became a formal term in the 1980s, with widespread national-level programs across Europe in the 1990s. TF focused on long-term challenges and innovation systems.	Growing global concerns about environmental sustainability, STI budget pressures, and innovation-driven economies.
2000s onward (9/11, Great Recession, geopolitical conflicts, climate change impacts)	Concepts like Responsible Research and Innovation (RRI) emerged. TA became more constructive, addressing early stages of technology development with broader participation and a focus on grand challenges. TF tools were integrated.	TF became more widespread, adopted by subnational and regional bodies. It shifted toward problem-driven foresight, especially around grand challenges, incorporating issues often addressed by TA.	Increased urgency for sustainability, security, and grand challenges drove further integration of TA/TF in policy development.

1.4 Technology Assessment and Foresight as Systematic Activities

TA and TF exercises to inform policymaking can be organised in many ways, and the specific approach to be taken will depend on the context. If it is the first such exercise, then it may make sense to undertake a review of available approaches and even to carry out one or more pilot studies, to get a sense of how fit for purpose the tools and outcomes look to be, what capacities need to be built, and just how to launch the main exercise.

If it is not the first exercise, then there is the option to repeat the approach taken in the earlier programme, or to learn from its limitations and try something new. Hopefully, capacities will have been established through the previous work, and there will be better understanding of the costs and opportunities associated with using external consultants and researchers.

Many countries institutionalize their TA and TF efforts, often assigning responsibility for both to the same body, which sets up a dedicated unit to manage the process. Whether this unit employs in-house practitioners or outsources significant parts of the work to external experts is less important than ensuring that the TA/TF activities remain closely connected to senior policymakers. It is crucial that these policymakers are kept informed of the progress and results, and ideally, they should be actively involved by attending workshops or chairing meetings.

Both TA and TF are, of course, activities that extend over time—they cannot just happen in a flash. They involve processes, which may be conducted as one-off exercises, or as parts of ongoing programmes of work organised by specific institutions. There are various accounts of the different steps involved in these activities, and Table 3 draws on these in comparing the approaches commonly adopted in TA and TF. The content of the stages outlined can be to some extent reorganised, but these are indicative accounts of the processes.

The exercise will require overall project management, of course, with initial planning establishing what steps are to be taken when, how and by whom, ongoing management monitoring the progress toward accomplishing each step and intervening if there appear to be problems. Project management and execution of the work may be carried out by an in-house team or contracted out to greater or lesser extent to external consultants, including various academic and private sector bodies.

Different methods may come into play across the different stages of the processes, and a wide range of different tools and techniques are available to help.[28] Some of these are designed to support groupwork in creative activities such as scenario development (e.g., brainstorming, scenario methodology). Others are intended to assist data analysis and forecasting by means of statistical or simulation modelling (e.g., trend extrapolation, systems dynamics). Some methods focus on gathering and synthesizing expert opinions and judgments, such as the Delphi method, while others facilitate the visualization of alternative futures and the exploration of their dynamics, such as gaming and persona method.

Additionally, some other methods support the mapping and appraisal of policy options (e.g., roadmapping). These techniques may be more or less quantitative or qualitative, with some oriented toward asking, "what if?" (so-called exploratory techniques), while others toward "how might this happen?" (so-called normative techniques). They may be reliant on expertise, or aim to engage numerous stakeholders, and may seek to inspire creativity or to follow algorithms.

> To be effective, TA and TF should be institutionalized **to ensure close engagement with policymakers**

28 Contribution from the United Nations Economic and Social Commission for Western Asia (UN ESCWA).

Table 3
The TA and TF processes compared

Stage in Process	Technology Assessment (TA)	Technology Foresight (TF)
Scoping ↓	Determine objectives of the assessment: What technologies or applications are the focus? What criteria are critical? What is the need for new technology?	Determine focal topics for TF (usually in consultation with the client): What is the span of technologies or issues? What is the time horizon? What stakeholders should be involved?
Initial Intelligence ↓	Map key features of the technology or application. Identify the current state of development and diffusion, leading and lagging uses, scope for stabilization of designs and platforms.	Scanning Phase: Examine drivers and trends, apply horizon-scanning methods, consider weak signals, and use tools like Delphi to gather expert opinions.
Exploring and Modelling Interconnections ↓	Outline potential and probable implications across various fields (beyond just key criteria), and how they might interrelate. Consider reactions to change, unanticipated consequences, and unintended impacts.	Develop models of change using ‘soft systems’ or similar methods. Develop alternative scenarios to outline plausible futures for technology development and use.
Analysis/Visioning ↓	Use multicriteria analysis or trend impact analysis to quantify and contrast impacts across different areas.	Outline an aspirational scenario: key features of a ‘stretch target’ for desired outcomes.
Appraisal ↓	Compare costs, benefits, and risks of different actions (including inaction). What are the implications for risk management?	May involve creating a roadmap for development and action over future years. Prioritize areas for policy action or specific interventions in the near term.
Recommendation ↓	Identify main policy recommendations based on the assessment. Document and justify them using the materials developed in earlier stages.	Similar to TA, develop clear recommendations for action based on findings.
Dissemination ↓	Prepare a suitable range of outputs, summarizing results for key stakeholders. Develop a detailed report for the main client and execute follow-up activities.	Disseminate outputs for policymakers and stakeholders, ensuring clarity of results and necessary follow-up.
Reflection ↓	Reflect on the extent to which the TA exercise has generated useful results. Assess its effectiveness in informing policy, raising stakeholder awareness, and driving action. Draw lessons for scoping, designing, and managing future exercises.	Consider how well the TF exercise informed policy and stakeholders. Reflect on lessons learned to improve future exercises.

Note: Though the stages outlined above suggest a very linear process, in practice there may well be reiteration of stages and reappraisal of earlier analyses and proposals as the activity is implemented.

Both TA and TF utilize a mix of quantitative and qualitative methods, though their emphasis often differs. TA typically leans more towards qualitative approaches, including expert interviews, stakeholder consultations, and case studies, to evaluate the broader impacts of technologies. These qualitative methods offer a rich, contextualized understanding, capturing the nuances and complexities that quantitative data alone might miss. However, quantitative data remains crucial in TA, providing empirical evidence and measurable indicators that complement and reinforce qualitative insights.

In contrast, TF often employs more quantitative methods, such as trend analysis, modelling, and statistical forecasting, to predict future developments and evaluate various scenarios. Policymakers frequently seek clear, quantitative answers from TF and TA reports, often asking for specific numbers and preferred scenarios. However, data must be contextualized, a process that is inherently complex and may not always yield straightforward answers. Thus, integrating quantitative and qualitative approaches in both TA and TF is essential for delivering comprehensive insights. This integration involves combining empirical data with detailed contextual analysis to fully capture the range of technological impacts and future possibilities.

There has been significant interest in computer modelling and large-scale data analytics, especially for identifying emerging trends in patenting and scientific literature. Many TF exercises now use these methods routinely. However, reliance on such techniques carries the risk of alienating users and participants, as the underlying methods can be complex and unfamiliar. The results may either be overly complicated or oversimplified.

The growing focus on participatory technology assessment (pTA) and broader stakeholder involvement in TF has shifted attention towards more qualitative and creative approaches for conducting analysis, facilitating discussions, and presenting results and recommendations. Bringing relevant stakeholders into TF and TA processes opens up the process beyond scientists and can make them more reflective of the views and experiences of relevant stakeholders who are not experts. This makes the process more inclusive and more embedded within the realities of society and the local context. Inclusivity also means recognizing that the effects of technologies across society are generally not neutral. Accordingly, there is a growing momentum behind inclusive TF and TA methodologies and exercises that address gender and other important social attributes to capture the diverse ways technologies affect different groups.

Cultural representations of emerging technologies, such as those in films, novels and even videogames, can provide compelling ways of depicting possibilities. This trend is not limited to Northern and Western contexts. There has also been a growing interest in equity-based perspectives in both TF and TA (e.g., Afrofuturism), emphasizing the importance of diverse narratives in understanding and shaping the future of technology (Mohamed *et al.*, 2020; Womack, 2013). While many cultural products only present one future scenario, the methods used can be applied to, for example, creating and “storyboarding” alternative paths of development.

For this shift towards more inclusive foresight practices, it is essential to ensure a diversity of experts—incorporating multidisciplinary perspectives and insights from both women and men, as well as marginalized communities, on socio-technical issues—especially during the initial scanning phase, where a long list of technologies is compiled for further analysis. If the range of perspectives in this phase is too narrow, there is a risk that the interpretation of *weak signals* (early indicators of emerging trends) could be skewed by influential experts. This can lead to the dominance of certain viewpoints and the exclusion of alternative, potentially valuable insights.

TA and TF both utilize quantitative and qualitative methods, **but their emphasis often differs**

TF now often employs **computer-modelling and large-scale data analytics**

Shifting towards more inclusive TA practices should allow responsiveness to gender and marginalized social groups

2. ROLES OF TA AND TF IN STI POLICIES AND SUSTAINABLE DEVELOPMENT

TA and TF can both make a significant contribution to effective STI policy and to promoting more sustainable development across countries, although they certainly do not, on their own, offer a silver bullet to solve sustainable development challenges. Each has contributions to offer. For some rapidly changing technologies both may be needed to offer strategic intelligence in the short–to–medium term, and for the longer-term, respectively. They are in any case highly complementary. Integrating their use can support national efforts to transition to more sustainable trajectories. They provide forward-looking evidence, but the actual choices made and the strategies implemented remain political issues. Through participatory approaches they can support more inclusive policymaking processes, but may reveal stakeholder disagreements and opposition where consensus cannot be reached. Where technologies evolve rapidly, there is pressure for TA and TF exercises to be more agile and rapid in providing strategic intelligence for policymakers. Digital technologies can facilitate faster and more sophisticated exercises, but more rapid methodologies will also be required, while maintaining more classic approaches where appropriate. For countries with limited experience so far with TA and TF, international cooperation will be needed to help them build capacity in using these tools.

2.1 Shaping Policymaking

TA can play a significant role in shaping national and industry-level policies, since it is intended to inform decision-makers with information about current technological choices and emerging technologies that may come into play in the near future, including insights based on a mixture of evidence and expert judgement about potential costs, benefits and broader implications of the uptake of these technologies.

TF typically takes a longer-term perspective, additionally providing insights into technologies that are liable to be of considerable importance in decades to come, but that should not be left for the future to deal with. Decisions made in the present can enhance preparedness to adopt and adapt these technologies, and, where possible, contribute to their production and design. Thus, R&D at early stages of technology development may be a key issue, and TF can inform STI policy as to areas where support of one kind or another may be required.

Various areas of policymaking, and types of policy, can be informed. The policymaking process, where STI issues arise, may be itself reshaped. This can involve better dialogue between parts of government where these issues are of wide significance, and dialogue between government and other key stakeholders including academia, the private sector and civil society. It can also involve better use of sources of knowledge (and capacities for action) that lie outside of government.

One important role of TF has been to help various government departments and agencies coordinate their efforts to achieve long-term change in addressing problems that require cross-sectoral policy responses. A case from the UK involved flooding, the subject of a problem-driven TF exercise, where government departments responsible for housing and construction, roadbuilding, management of river and coastal environments, emergency services, and more were engaged. That project was also of great interest to the insurance industry, with its analyses feeding into that industry's strategic planning. Likewise, a TF exercise addressing obesity engaged those responsible for sports, food, education and health—and to which the food industry reacted in a less accommodating manner.[29]

A second important role of both TA and TF is establishing better communications between expert and policymaking communities (Amanatidou, 2014). In large societies, especially, it may simply be a matter of members of each type of community knowing better whom to liaise with in the other. Typically, these exercises engage a diverse range of experts and knowledgeable stakeholders to address issues related to specific technologies or grand challenges. In addition to providing immediate insights into expert opinions and data, the networks established through these efforts are likely to serve as valuable resources for addressing future policy matters.

TF also helps improve communication **between experts and policymakers**

29 Obesity raises numerous questions in the realms of science, technology, and innovation. While some causes lie in diet—where innovations in the food industry are blamed for fostering poor eating habits and prompting calls for research into food standards, labelling, and the creation of healthier foods—socio-economic factors also significantly impact obesity rates. Issues like limited access to nutritious food, lack of education on healthy lifestyles, and economic disparities contribute to the problem, leading to public measures such as community health initiatives and policy interventions. Additionally, some commentators and sufferers highlight genetic predispositions, pointing toward pharmaceutical or surgical solutions.

TF programmes have reshaped funding decisions **by anticipating technological disruptions in ICT and biotechnology**

2.2 Immediate Decisions versus Strategic Planning

When it comes to inputs on STI policy, TA, which is oriented toward current and emerging technology issues, typically informs immediate policy decisions. It does this by providing insights based on empirical evidence, or expert judgement augmented by wider stakeholder inputs, on topics such as the relative costs and benefits of different technologies, health and safety issues, or on immediate regulatory requirements.

TA may draw on concrete evidence from observations of the early use of new technologies—especially if other countries have introduced them earlier—or on analogous historical experiences. It may also promote more detailed empirical studies, such as surveys of users. TA can bring together individuals with experience of current use and those involved in designing systems and planning the adoption of such systems in various organizations. For example, in the adoption of augmented reality (AR) technologies on a factory floor, TA might engage machine operators familiar with manufacturing processes, engineers designing AR solutions, and production managers overseeing operations (Seeliger *et al*., 2023). This approach ensures that the AR technology enhances productivity without compromising quality or worker safety and integrates seamlessly into existing production workflows.

In contrast, TF informs longer-term strategic planning and decisions about "upstream" technology development or adoption, such as where R&D funding might be allocated across the spectrum of areas of strategic research, especially when the boundaries between pure and applied R&D are less apparent. Many of the initial wave of TF programmes in the 1990s and 2000s were oriented, at least in part, by the need to concentrate limited financial resources across different areas. This remains an important orientation for some developing countries that have recently implemented ForSTI exercises (for example, South Africa,[30] Mauritius[31] and Botswana (UNCTAD, 2023, 2024d)).

Established ways of determining and allocating funding were disrupted by new technological developments that were insufficiently anticipated and addressed in existing STI policy, particularly in ICT and biotechnologies. These TF programmes had significant impacts on funding decisions in many countries, and in some cases led to ongoing '*technology watch*' initiatives to monitor changes in the landscape that might require attention. Additionally, they identified areas of technological opportunity, including medium-term prospects and emerging fields that required long-term investment. The programs also highlighted strengths and weaknesses in national innovation capabilities, helping to pinpoint where and how these could be developed. They were instrumental in identifying priorities for funding R&D, demonstration projects, training, and support for innovative businesses.

TF exercises could also pinpoint where wider international cooperation might be necessary. One example of such TF impacts is the case of quantum computing. In 2018, Germany's Federal Government commissioned an expert panel to develop a roadmap outlining future development steps. Since then, the BMBF has funded collaborative projects under the program "Quantum Technologies – From the Basics to the Market," and a national competence network was established in 2021. Recently, the Federal Environment Agency identified quantum computing as a key issue for

30 For more information, refer to the foresight reports available at https://www.naci.org.za/index.php/foresight-reports/.

31 There was also an effort at ForSTI in Mauritius in 2012-13. Although few details have been published, refer to the document available at https://www.repository.mu/mrc/out/out.FrontDocumentDetails.php?documentid=683 .

environmental policy, warranting further TA-type analysis (Jetske *et al*., 2022).

Beyond immediate health and safety issues, TF may point to potential risks and challenges that may emerge and become evident in the longer-term. This can lead to planning for risk management and resilience, as was the case in the potential large-scale outage of electric power. Some new technologies may be dependent upon systems and infrastructures that are vulnerable to serious disruption, and widespread use of such technologies may involve this dependence becoming prevalent.

For example, computer-communication systems are vulnerable to malevolent actions (e.g., cyberextortion, ransomware), natural disasters (e.g., solar storms affecting satellite communications—the threat of superstorms such as the "Carrington event" is recognised by IT system planners), and outages due to human error or accident. STI policy may need to include strategies for resilience to such disruption. Preparedness to address potential risks could help facilitate public acceptance of new technologies, even though technology proponents may be averse to public discussion of such risks. Another challenge is the problem of scale. While TA/TF often operate at a national level, many potential risks are international in scope. This mismatch can hinder effective risk management and public engagement. Bridging this gap requires coordinated efforts that transcend national boundaries, emphasizing the need for international collaboration in TA/TF activities.

TA/TF can help identify technologies that are well-suited to a country's specific needs and the maturity of its National Innovation System (NIS) (Box 3).[32] By grounding technological innovations in national socio-economic and innovation capacities, TA/TF can contribute to the development of more resilient and future-proof industrial policies.

TA/TF identify technological opportunities, risks, and strengths **in national innovation capabilities**

While TA/TF are particularly valuable for developing countries in their efforts to catch up or leapfrog to more advanced stages of economic development, TA/TF are also highly relevant for developed economies. For example, many EU countries focus on mature technologies with limited potential for breakthroughs, and, as a result, they tend to invest less in STI compared to countries pushing the technological frontier and experimenting with emerging technologies (European Commission, 2024). TA/TF can provide developed nations with the strategic intelligence needed to challenge the status quo and reinvigorate productivity growth through technological change.

Moreover, TA/TF can also be valuable tools for balancing the trade-offs between short-term economic gains and long-term sustainable development. By proactively assessing the potential impacts of emerging technologies, they can ensure that immediate and long-term impacts of the adoption and use of technological innovations do not compromise the SDGs.

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32 The concept of a National Innovation System (NIS) refers to the network of institutions, policies, and practices that influence a country's ability to generate, adopt, and diffuse innovations (Freeman, 1987; Lundvall, 1992; Nelson, 1993).

Box 3.
Technology Assessment and Foresight in India

India's approach to TA/TF is largely driven by the work of the Technology Information, Forecasting and Assessment Council (TIFAC). TIFAC, which aims to enhance India's global competitiveness and sustainable development, conducts expert-led, technology-oriented studies that include technology forecasting, evaluation of alternative technologies, and sectoral issues analysis (Srinivas & van Est, 2023). TIFAC's recent TA publications analyze electric two-wheeled vehicle adoption, examine trends in telemedicine, and explore climate-related technologies across sectors.

India's participatory TA practices, although limited in government initiatives, include notable efforts such as the Bt brinjal consultation, which led to a moratorium on genetically modified aubergine plants in 2010 following significant public debates. Civil society-driven bottom-up initiatives also contribute to TA, especially in agriculture, where the Indian Council of Agricultural Research addresses adaptation needs, including a gender assessment that explored ways to alleviate drudgery for female farm workers.

India's strong STI culture makes it more likely that TF work will be undertaken there,[33] with new actors appearing in the field such as the Centre for Technology Foresight and Policy at the Institute of Technology in Jodhpur. With initiatives like TIFAC's Technology Vision 2047, the country emphasizes long-term technological roadmapping and climate change strategies. TIFAC's TF work spans diverse sectors, from "Climate-Smart Agriculture" to telemedicine, using interviews, surveys, and validation workshops to engage stakeholders. Additionally, TIFAC offers training in scenario planning and Delphi methods, emphasizing demonstration studies to inform policymakers and foster stakeholder involvement from the outset. In general, TIFAC tends to focus on shorter rather than longer term foresight.[34]

Overall, India's TA/TF efforts reflect a blend of expert-driven analysis, participatory initiatives, and a deeply rooted culture of TA/TF to advance strategic national goals in sustainability, climate resilience, and technological self-reliance.

33 Contribution from the Government of India.

34 Goswami, G. & Ayyaswamy, J. (2021). Foresight Practices in India – An Overview. https://issek.hse.ru/mirror/pubs/share/595547704.pdf.

2.3 The Evolution of TA/TF in the Context of Sustainable Development

Both TA and TF, along with broader STI policymaking, have in many countries, especially developed countries, evolved from a predominantly technology-centric focus to a more problem-oriented approach. This shift towards greater directionality[35] of STI policies is characterized by an increasing emphasis on proactively designing solutions for global grand challenges[36] (Kuhlmann & Rip, 2018).

These challenges are no longer seen as purely technical problems; rather, they require multi-dimensional solutions that account for social, economic, and environmental factors. For instance, ensuring global food security goes beyond simply increasing agricultural output. It necessitates addressing inefficiencies in food distribution, curbing food speculation, promoting sustainable farming practices, and considering the effects of climate change on crop yields.

These complexities highlight the need for solutions that are holistic and system-oriented. This is where the shift toward systems thinking in TA and TF becomes critical. Instead of isolating individual technologies, both fields now focus more on analyzing a portfolio of technological solutions and their interactions within broader value chains and systems.

Other terms like **mission-oriented innovation policies** are widely deployed to emphasize the strategic direction of R&D efforts towards specific goals (Mazzucato, 2018). Mission-oriented innovation policies can be defined as "a co-ordinated package of policy and regulatory measures tailored specifically to mobilise science, technology and innovation in order to address well-defined objectives related to a societal challenge, in a defined timeframe" (Larrue, 2021). An example is the development of clean energy technologies to reduce carbon emissions, which requires coordinated efforts in research, industry collaboration and supportive policies. There are growing calls by innovation studies researchers for more experimentation and a **moonshot mentality** in STI policies (Kantor & Whalley, 2023). This refers to setting ambitious, seemingly impossible goals that require radical innovation and can inspire collective action. Adopting a moonshot mentality means being willing to invest in **high-risk**, **high-reward** projects that have the potential to bring about transformative change.

However, while the emerging shift in TA/TF practices and broader STI policies toward addressing grand challenges and providing targeted solutions aligns with sustainable development, this emerging challenge-solution framework can also have unintended consequences. As Ludwig *et al*. (2022) argue, framing innovation solely around predefined challenges risks generating short-term, technocratic solutions that focus on immediate symptoms rather than addressing underlying systemic issues.

One of the main dangers of the new paradigm in STI policies, and the role of TA/TF within it, is that it could promote innovation within the constraints of existing socio-economic and political systems. This can perpetuate unsustainable practices by failing to consider the broader structural transformations required to truly achieve long-term sustainability. For example, focusing on incremental technological improvements, such as developing cleaner technologies, might overlook the more profound need for restructuring the global energy system, including changes in consumption patterns,

TA and TF have shifted from technology-centric approaches **to problem-oriented, system-level solutions**

TA and TF help design transformative, mission-driven innovation policies **addressing grand challenges**

Innovating within the confines of current systems risks maintaining unsustainable dynamics leaving systemic challenges unresolved

35 Directionality refers to the deliberate steering of STI policies toward specific societal or economic goals, rather than relying on market forces or scientific advancement to determine the direction of innovation.

36 For example, the Bipartisan Infrastructure Law and Chips and Science Act in the US also put "solutions" at the centre of a more activist STI policy.

governance, and equity. Innovating within the confines of current systems thus risks maintaining entrenched unsustainable dynamics and leaving underlying systemic challenges unresolved.

There has been a recent push towards the development of transformative innovation policies that target underlying sociotechnical systems to create deeper transformative changes to meet societal challenges and promote sustainable development (Diercks *et al*., 2019; Schot & Steinmueller, 2018). In this context, TA and TF can play crucial roles by identifying pathways for structural change.

Both TA and TF encourage a culture of experimentation and continuous learning

However, supporting transformation through TA and TF also requires grappling with the inherent value conflicts and ambivalences that arise in STI policymaking. Technological solutions often carry social, cultural, and political implications that can lead to disagreements among stakeholders and resistance. Therefore, TA/TF practitioners are advised to adopt an "**honest broker**" approach (Pielke, 2007), which involves *expanding policy options*, rather than pushing for a single technocratic solution that fails to see how STI initiatives could intensify political and cultural value conflicts that undermine governance and, by extension, sustainability. For example, the promotion of genetically modified crops or large-scale renewable energy projects may be seen as technological advancements, but they can generate opposition from communities concerned about environmental impacts, economic inequality or public safety.

TA and TF identify systemic failures **and propose innovative governance solutions for transformative change**

The shift towards value-based and solution-driven STI policies also highlights the need for policy learning through TA/TF. This involves considering "**behavioural additionality**", which refers to how policy interventions influence the behaviours and associated values of the actors involved or impacted by them (Amanatidou, 2014; Magro & Wilson, 2019). Participatory TA, in particular, fosters public deliberation and co-creation, allowing citizens and civil society to influence policy directions. Both TA and TF encourage a culture of experimentation and continuous learning, which is critical for the success of transformative innovation policies. By embedding evaluation and learning mechanisms into the policy process, TA/TF practices allow for more real-time adjustments based on feedback and changing circumstances. For instance, policies can be adapted as new technologies emerge, or as the social and environmental impacts of current innovations become clearer.

In the context of transformative innovation policies that aim to rectify systemic failures, such as market inefficiencies or governance gaps, TA and TF provide the analytical tools necessary to identify these failures and propose out-of-the-box solutions to fix them. TA, by examining how technologies interact with existing regulatory frameworks, markets, and institutions, may highlight governance gaps that should be addressed in order to facilitate systemic transformation. Similarly, TF can aid in exploring new governance models that can better support innovation ecosystems geared toward grand challenges, such as mission-oriented innovation policies that bring together public and private sector stakeholders toward common goals.

Both TA and TF can help to ensure that innovation policies are aligned with broader societal missions and stay on course. TA can assess whether specific technological innovations contribute to or detract from these missions, while TF can help set long-term strategic directions that align with these grand challenges. It is possible for a TF programme to combine both technology- and problem-driven approaches.

For example, Japan has institutionalized large-scale Delphi studies conducted regularly to guide STI priorities, demonstrating a sustained commitment to long-term foresight. In contrast, there appears to be less interest in large-scale Delphi exercises in many Western countries. Instead, ongoing foresight activities there have focused more narrowly on horizon-scanning and technology watch, often through targeted "deep dives" into specific technologies or problem areas, including issues related to the performance and structure of NIS.

TA and TF are complementary approaches when taking a more problem-driven focus, such as considering sustainable development, or particular aspects of it, like energy use. TA provides inputs concerning choices that can be made among technologies that are currently in existence, or which can be realised on the basis of available designs. TF provides views of plausible future trajectories and capacities, assisting in long-term strategic planning. For example, it can aid in decisions on investing in upstream R&D intended to create capabilities that address gaps in current technologies identified by TA.

The tools and techniques of TA and TF may be vital for informing policymakers and citizens about key issues and likely consequences of STI policy decisions, but do not in themselves possess decision-making power. They provide "strategic intelligence" that can be used to design, review and examine strategies (Robinson *et al*., 2021). However, making choices and implementation of strategies are political issues.

Energy as a subject for TA and TF

How might the TA and TF approaches be brought into play when confronted with specific aspects of sustainable development, such as patterns of energy production and use? TA is typically used when immediate decisions are needed, for example, regarding the location of power stations, the types of power production and distribution to be used, and the associated infrastructure.

Although these decisions are immediate, they can have long-term consequences, as the facilities involved often remain in operation for decades.[37] A wide range of costs and benefits need to be taken into account in making these decisions, which often impact various stakeholders very differently. These differential impacts make the decisions inherently political.

TA can help assess how well-founded the claims about costs and benefits are. It can identify consequences of decisions which vocal stakeholders may elide, such as environmental implications critical for sustainable development. Its exploration of public attitudes to specific developments may help clarify how far the resistance to change is a matter of very specific impacts on particular communities and how far there are wider principles and concerns at stake.

The sorts of argumentation and trade-off that may arise are very likely to differ from case to case, and when TA organisers can be trusted as "honest brokers" they may play a role in establishing shared appraisals of problems and solutions. Often TA will be undertaken with a sectoral focus, and it may be commissioned by a range of government departments and industry bodies.

While TA focuses mostly on the immediate implications of current or emerging technologies, TF typically has a longer-term focus, examining plausible developments in relevant technologies beyond the options immediately on offer. TF examines, among other things, the trajectories of relevant technologies, in terms of their features and performance. Some of the earliest technology forecasting, for example, examined and projected forward growth in the size and cargo capacity of ocean-going ships.

TA and TF provide strategic intelligence, **but policy decisions are made by policymakers**

While TA addresses current or emerging technologies, **TF explores longer-term technology trajectories and options**

37 Large and complex projects often encounter unanticipated issues once work has begun. Many such issues require revisions to estimates of benefits and, especially, the costs of particular systems. TA and policy formulation should take into account the possibility that some decisions may need to be reviewed over time. This brings risk management into play. How far is it possible to avoid locking the system into a particular framework, when there is a reasonable expectation that this framework might not be stable? Facilities, for example, might be designed, so that they could be adapted to better fit changed circumstances.

Understanding these technological trajectories is crucial because, in many areas of advanced technology, considerable changes in functionality can be expected over time. Some of these changes enhance the prospects that new technologies be able to better support sustainable development. They may be expected to be cheaper, demanding fewer inputs of energy and scarce resources. This is not inevitable—some technology applications change very slowly, while trajectories may have negative features. For example, AI requires substantial increases in energy consumption (UNCTAD, 2024c).

Some well-resourced national governments deploy various tools to develop and apply knowledge in addressing environmental concerns and SDGs (Box 4). They can use regulatory and other measures to influence markets, e.g., tax relief, subsidies, and public procurement. This can influence technological trajectories, as demonstrated in the case of solar panels and other renewable energy technologies (cf. OECD (2012) which discusses "*bending*" technological trajectories).

Box 4.
The use of roadmapping and scenario planning in Fossil Free Sweden

The Fossil Free Sweden initiative is crucial in guiding Sweden's transition toward becoming the world's first fossil-free welfare state (UN DESA, 2017). It serves as a collaborative platform, bringing together stakeholders from various sectors to create detailed roadmaps that guide the transition to carbon neutrality by 2045.

These roadmaps are tailored to the specific needs of each sector, such as green steel production in the steel industry or energy-efficient building practices in urban development. The initiative ensures that these plans are both ambitious and realistic, addressing technological, financial, and regulatory challenges through extensive stakeholder engagement.

In addition to roadmap creation, the Fossil Free Sweden initiative facilitated scenario planning, helping stakeholders explore different future pathways and prepare for various outcomes. This process considers technological advancements, policy changes, and global trends, ensuring that Sweden's strategy for becoming fossil free is resilient and adaptable.

TF explores plausible energy futures, informing strategic investments in R&D, infrastructure, and systemic change

In addition to examining patterns of technological change, TF will typically consider the social and economic contexts in which this change may unfold. Accepting that medium- and long-term futures are highly unpredictable, TF will typically consider alternative futures, and how these might come into being. The emphasis will be on plausible futures —ones that deserve to be taken seriously, and that do not rest upon "*wild card*" breakthroughs in technology or changes in society (Miles *et al*., 2016).[38]

Furthermore, TF will usually involve enlisting engagement from a wide range of stakeholders, who are able to bring their knowledge to bear on matters ranging from the state of laboratory research and innovation financing to the development of markets and product lifecycles. These stakeholders may play important roles in the wider dissemination of the insights deriving from the TF exercise—not least those insights about how different stakeholders would be prepared to respond to change,

38 Wild cards are generally understood to be low probability but high impact events. They should be considered by those concerned with resilience and risk management. The German TA study of power outages is an example of application of this approach to a wild card, though the plausibility of such a disaster was seen as uncomfortably high. TF can feed into these activities, since new technologies or scientific discoveries may change perceptions of the likelihood of events.

and about how far development is moving in the direction of one scenario or another.

Both approaches would draw upon data concerning current patterns of energy production, distribution and use. This requires examination of the systems that produce or access via trade, forms of energy such as electricity and the energy embodied in fossil fuels. The distribution and storage of various types of energy resources is also critical—for instance, the nature of electricity grids, and issues of power storage (e.g., via batteries, pumped storage hydropower).

Usage patterns of various sorts of energy across different sectors of the economy and by households are a third component of the overall socio-technical system. Decisions on whether to maintain or transform these patterns are longstanding—power stations and coal mines, for example, have finite lifetimes—and may often be controversial, particularly because of trade-offs between risks to employment, to human health and natural environments. Consumption and storage issues may also be subjects of policy, as seen in efforts to increase usage of electric vehicles and to reduce energy wastage in domestic settings.

The sustainable development context leads to pressures for a reduction in fossil fuel use, and thus the criteria employed in technology choice are changing. TA may be used to compare and contrast available technologies when decisions are being made in terms of power stations (including renewable sources such as solar, tidal and wind power) and power storage (including new battery facilities, fuel cells and pumped-storage hydropower) systems. TF may be used to project trends in the costs and efficiency of such systems over a longer-term and examine alternative technologies that are coming over the horizon where R&D efforts may generate quite new solutions to old problems.[39]

Alongside assessment of the development patterns of energy production and consumption, more sustainable development-oriented initiatives require TA examination of the scope for energy efficiency and for other changes in patterns of energy use. The latter might involve socio-technical and organizational changes, such as sharing economy solutions, pooling of facilities across households, combined heat and power systems, and decentralised production.

TA typically needs to consider inequalities that are liable to emerge or be reinforced between regions, communities, social groups, or genders, when socio-technical changes affect the differential domestic work and formal employment circumstances of men and women.[40] TF may consider how changing opportunities and costs may promote—or be inhibited by—generational shifts in relationships in the family and in working lives.

TA and TF must consider how socio-technical change **may reinforce or reshape social inequalities**

Like most of the large systems serving important socio-economic functions, the energy system is complex, with multiple technologies and stakeholders. Policy decisions can benefit from examination of both immediate contingencies and longer-term trajectories. The two approaches are complementary, but at any given time, decision-making may require more of a TA or more of a TF orientation. Decisions about the siting of new power stations (including those based on renewables) may be more informed by TA, for example, while decisions about R&D and training may be more informed by TF. Both TA and TF can draw upon some of the same resources, such as stakeholder analyses, reviews of technology options, and appraisals of the current structure of the energy system.

39 Contribution from the United Nations Environment Programme (UNEP).

40 See the work of UNDP on gender inequality and energy: https://www.undp.org/energy/our-work-areas/energy-and-gender-equality. For a discussion on Technology Needs Assessment that incorporates gender considerations, including energy technologies, refer to UNEP DTU Partnership, available at https://unepccc.org/unep-dtu-partnership-at-cop-and-beyond/.

TA can catalyze transformative policy reforms and public debate **to strengthen resilience of public infrastructure**

Vulnerability and Resilience of Critical Infrastructures

Infrastructures are the backbone of modern societies and economies, enabling everything from transportation and energy to communication and healthcare. Yet in recent years, their fragility has become increasingly evident, highlighted by the cascading impacts of the COVID-19 pandemic, terror attacks, wars, extreme weather events and cyberattacks. These crises have exposed critical vulnerabilities across sectors, prompting growing concern about infrastructure resilience.

According to Grunwald (2018), one TAB study (Petermann *et al*., 2011) on the consequences of large-scale outage of the electricity supply "caused something like a shock-wave in many municipalities, state, and federal ministries and authorities". The study investigated the consequences of such a blackout by applying a rather simple methodology. It analysed the consequences in the form of *if/then chains*[41] and asked the question: If such a blackout occurred, *what* would happen and *when*? For example, what infrastructure functions would no longer be available, and which consequences would occur subsequently. Several of those if/then chains were developed and form a kind of map of what would happen where and when. The if/then chains were generated by the Office of Technology Assessment at the German Bundestag based on expertise from scientific institutes.

Several results were quite alarming. For instance, the water supply infrastructure would immediately break down in some areas of Germany, with the consequence that there would be no access to water in private households which would cause extreme hygiene problems at short notice. Hospitals would be over-burdened because other medical institutions, like dialysis stations, usually did not have diesel generators to replace electricity. It became obvious that Germany was prepared poorly for such an event and that the consequences of a prolonged and widespread power outage would amount to a particularly serious hazardous situation with the risk of societal collapse.

One notable feature of this TA exercise is that the focus was not so much on an emerging technology, as on the trends toward increasing reliance on a technological infrastructure. The implications of vulnerabilities in this established technology were certainly worthy of assessment, and the exercise was regarded as being transformative in the policy responses it triggered, which led to a review and reformation of Germany's civil protection system. The work also created public debate, which underpinned the political demand for action to enhance the resilience of the socio-economic system.

Currently, there is renewed interest in the vulnerability of critical infrastructures in governments across the world. In the context of numerous crises and disruptions, the need for the horizon-scanning and orientation function of parliamentary TA became increasingly important. TA offices tend to expand into more foresight-oriented activities, adding a *resilience radar* and an *in-depth resilience check* to its existing advice portfolio.

Roles of TA and TF in Sustainable Development

Sustainable development is a topic that cuts across many areas of government and considering it as a topic only for Ministries of Environment is evidently insufficient. However, problems of coherence—**a lack of 'joined up government'** (e.g., Carey & Crammond, 2015)—are also often encountered when different aspects of

41 The if/then chains method is a logical approach used to analyze and predict outcomes based on conditional relationships. In this method, a sequence of events is mapped out in a chain-like format, where each step follows the "if X happens, then Y will occur" structure. It is often used in risk assessment, scenario planning and systems analysis to understand the potential consequences of certain actions or events.

sustainable development are parcelled out across different ministries or government departments without coordination. At the very least, coordinating methods need to be employed, and knowledge of problems and policy options shared. TA and TF can contribute to such exchange. For example, they can engage policymakers from different agencies into joint workshops and discussions, so that they exchange knowledge of each other's problems, resources, timetables, in addition to gaining more general knowledge of development-related social and technical issues from the TA/TF.

One initiative that many countries may pursue is the establishment of enhanced systems for monitoring and reporting progress at national, regional and sectoral levels. Another important aspect is integrating TF activities—such as horizon scanning and scenario analysis—with the processes involved in creating and implementing roadmaps for sustainable development policies (Japan Science and Technology Agency, 2021).

Reviewing the alignment of national research funding with the SDGs would be a step towards understanding how STI policies contribute to and support sustainable development efforts, but the policy mix extends well beyond R&D funding. While some research funding may be aligned with sustainable development—directed, for instance, toward providing clean water, enhancing agricultural sustainability, or creating affordable medical technologies—the broader policy landscape may include many other elements that influence progress toward the SDGs.

Sustainable development action raises issues of financing and market development, technology transfer and the potential dangers of technology dependency, and the environmental impacts of technology application. Beyond the achievements of R&D, there are often difficulties in scaling up and deploying sustainable technologies. This applies to technologies that are already on the shelf as well as those developed through new R&D. The diffusion and use of innovations is often particularly relevant when it comes to SMEs, who may lack the knowledge and resources to take them up.

More generally, inclusive STEM education at all levels can seek to build awareness of the SDGs and encourage development of relevant skills. These include general systems thinking awareness as well as training in emerging areas of science that bear on sustainability and specific issues such as biodiversity, and the circular economy. One aim is to build local capacity to choose and to adapt technologies, and hopefully to enable more local and bottom-up innovation. This requires a range of capabilities from improving basic awareness of STI issues in general to developing skills appropriate to conducting TA and related appraisals.

There are examples of TA being applied to assess technology development that offer opportunities to reduce disadvantages faced by specific social groups, such as enabling disabled people to work from home or helping partially sighted or blind people navigate through cities. Gender issues also intersect with these initiatives, particularly in terms of women's access to STEM education and the need to assess how specific technology choices impact women. Globally, women are less likely to access the internet, own a mobile phone, or have digital skills, and AI systems often embed gender biases, potentially marginalizing women further.

Technological change does not affect men and women equally. Employing gender-responsive methodologies that utilize data disaggregated by gender as well as other important social attributes can help facilitate the identification and mitigation of unequal gender and other social impacts. Inclusive innovation, which pays attention to marginalized groups, can lead to the development of affordable and accessible "bottom of the pyramid" technologies. These types of constructive TA practices are clearly valuable. However, TA often tends to focus on risks and

Technologies may impact social groups differently and methodologies adopted should be responsive to this costs as immediate concerns, rather than on long-term issues of socio-economic inequalities, likely because these are the issues that policymakers typically prioritize.

Together, TA and TF have the potential to support a balanced approach that addresses immediate needs while building future capabilities. The two approaches ideally should be integrated, and in some cases the same agencies and sets of expertise are involved in both approaches. This seems to be the case to some extent, at least, in Brazil, Peru and Germany, for example. But TA and TF exercises are typically commissioned by and for different sets of policymakers, reflecting the generally different institutional arrangements in place for TA versus TF.

More integrated TA and TF can support sustainability transitions by fostering inclusive dialogue and improving understanding

TA often relates more to parliamentarians and others concerned with making and reviewing more immediate decisions about the choice of technologies, their impacts and the ways they are employed. TF often reports to central planning agencies concerned with longer-term strategy. The activities may be conducted in silos, without sufficient information exchange to integrate their contributions.

More integrated approaches should aid navigation of the inevitably complex transition to sustainable development, in which the use of STI plays a major role. The two approaches share some attributes:

1. Both can facilitate inclusive dialogues on the adoption of specific technologies and the development path that is implied.
   - Both can help improve the public's and policymakers understanding of STI choices and options, and of wider social, environmental and ethical issues.
2. Both introduce evidence into policy discussions that may traditionally be made on the basis of personal hunches and assumptions.
   - Both may support the efficient allocation of limited resources, though for different aspects of STI development. Additionally, both may provide input for planning regarding skills development and infrastructure activities as well as overall strategic planning.
   - Finally, both can benefit from international cooperation, including regional and South-South cooperation. Such cooperation may also enhance capabilities to negotiate technology transfers, to move beyond being passive consumers of foreign technology, and to learn about and master key aspects of the underpinning science, technology and innovation.

TA and TF generally span different time horizons **but can converge towards the medium-term**

On the other hand, the two are often at opposite ends of a spectrum of time horizons, ranging from immediate and short-term technology choices to longer-term and strategic efforts, to revitalise the NIS around future STI opportunities. But their horizons can converge, especially within the medium-term of the spectrum where TA can operate and TF might also be utilized in fast-evolving areas. They share data and some of the analyses of technological change and its socio-economic implications and thus gain from being carried out concurrently. TA has the capacity to open TF practitioners' eyes to wider social dimensions of technology development and adoption, while TF may alert TA practitioners to longer-term transformations that could provoke yet more flux in socio-technical systems. These wider perspectives are liable to be valuable for policymakers as well.

TA typically focuses on environmental, social, and economic impacts of technology, but may include wider ethical, legal, regulatory and cultural implications, and this can be configured to stress assessment of these choices to the SDGs. It is quite likely to unpick potential conflicts across the various goals and objectives, and the risks associated with particular innovations. For example, it may outline where, and in what ways, contributions to economic development may cause environmental damage or negative impacts on equality or other social dimensions. This will often require bringing local knowledge to bear since imported technologies may not fit local circumstances without substantial adaptation.

TF can help create shared appraisals of a sustainable future, aligning the perspectives of policymakers and of a wider body of stakeholders, including, for instance, those in different regions or from different communities. Such shared views can include perspectives on where sustainable development might take the country, and what an SDG-oriented NIS would look like, with what interventions being needed to strengthen relevant capabilities. In some cases, TF is being used for priority setting. This can identify niche areas where the country can develop competitive advantages, and even point to scope for "leapfrogging". How does this fit into global technological trajectories and the establishment of global or regional "green technology" value chains that support sustainable development?

Exploring cross-sectoral connections can uncover potential synergies and mismatches. Scenario analysis can map out pathways toward sustainable development, providing alternative scenarios that highlight where preparedness and resilience are needed. Factors such as geopolitical conflicts and the impacts of climate change may hinder this transition. In this context, TF can help identify risks, as well as enablers and opportunities, thereby assisting in the preparation of proactive policies to address these challenges.

2.4 The Challenge of Rapid Technological Change

Attitudes to rapid technological change are diverse. Some commentators dispute the notion that technological change has generally accelerated, pointing out that some technologies have developed slowly while others have changed more rapidly. Others are no doubt tired of being told repeatedly that some innovation is going to bring about a technological revolution. Some argue that rapid change has been underway for centuries and point to 19th century writers who described the industrial revolution as "pandemonium" (Jennings, 1985). Some would argue that technological change can be punctuated by the emergence of successive new general purpose technologies, each of which underpins a cascade of changes in the organisation of many sectors of the economy (Bresnahan, 2010; Jovanovic & Rousseau, 2005; Trajtenberg, 2019).

This report takes the view that there is rapid technological change in many technology domains. Moreover, this pace of change is further accelerated at convergence points where established and emerging technologies intersect. Technological convergence often yields breakthroughs that would be unachievable within a single discipline alone, as advances in digital technologies, biotechnologies, and other technological fields increasingly overlap.

A recent example of this convergence can be seen in the awarding of Nobel Prizes in Chemistry and Physics to computer scientists in 2024. The integration of AI across diverse research fields illustrates how cross-disciplinary tools are driving breakthroughs and fostering rapid technological advancement. The convergence of technologies is not only transforming individual industrial sectors and research disciplines but is also creating entirely new paradigms, redefining the boundaries of scientific and technological progress.

TF can help create shared appraisals of a sustainable future, aligning perspectives of policymakers and other stakeholders

Opinions diverge on rapid technological change **as a generalized phenomenon**

TA and TF can enable a structured approach **to accessing a wider range of expertise**

Rapid technology change means that TA and TF issues may well suddenly hit the political agenda, as policymakers realize that they need to know about topics that had been assumed to lie over the horizon. Methods like Delphi are often employed to elicit information on what such experts deem possible and probable. Accessing a wider range of expertise than the established "usual suspects" can be very valuable here, since disruptive innovations often emerge from outside the currently dominant practices.

Access to relevant expertise may also be more difficult when the main activity in STI development is taking place in other regions of the world or other countries in the region. It can be useful to locate and examine the results of reviews and similar work carried out elsewhere, to determine in a timely manner whether the emerging topics require further examination. International organizations can often assist in this task. It may even make sense to send teams to visit experts and research groups overseas. Speedy evaluation of how far the issues examined elsewhere are pertinent locally, and exploration of whether additional issues may arise, can be organized. Thorough local TA and TF work may require more time to complete, and again it may be that regional or international cooperation can assist here (Hennen *et al.*, 2023).

TA and TF are both needed to address immediate and longer-term risks of rapidly changing technologies

In many cases, both TA and TF are required. Rapidly changing technologies may raise immediate issues, especially if they already offer attractive opportunities or pose significant threats. But as they change and evolve, further and potentially very different, issues are liable to arise. We can see this at present in the arguments around AI. Fears about the threats of long-term development of superintelligence may be diverting us from the very real risks of current AI use, such as programmed trading in stock markets, deepfakes and other use of AI for misinformation for political or criminal ends, and use of AI in weapons systems that make life-or-death decisions (Bremmer & Suleyman, 2023; Dwivedi *et al.*, 2021; House of Lords, 2023; Köbis *et al.*, 2021).

Future AI developments could pose existential challenges to humanity, making it crucial to address them proactively rather than waiting until it is too late (Bostrom, 2014; Suleyman & Bhaskar, 2023). While there is considerable uncertainty about how quickly and to what extent the more immediate impacts will unfold, much can be gleaned from trend analysis and historical analogies, such as job displacement during earlier waves of automation. However, longer-term developments—whether positive or threatening—remain far more uncertain, ambiguous and controversial.

At the same time, it is important to note that many novel technologies take quite long periods to finally reach widespread application through technology diffusion. Indeed, some innovations that have been hailed as being transformative have turned out to have relatively limited uptake outside of specific niches. The notion of the "hype cycle", where there is a burgeoning of initial excitement about an innovation, followed by disillusion and then by gradual recognition of its real value, is a useful, if imprecise, way of thinking about this.

For this reason, TA/TF experts are liable to be very cautious when it comes to adopting the optimistic excitement of proponents of new technologies, or the apocalyptic fears raised by opponents. It is undeniable that technologies such as electrification, electronics, and microelectronics have been of pervasive importance and continue to underpin exciting new developments like AI. Biotechnology, once seen by some as a prime example of "hype," is now finding substantial applications in sectors like health and agriculture. New fields of biotechnology, such as synthetic biology, are also opening up radically new possibilities for novel products and processes. Nanotechnology and advanced materials may still be in the disillusionment phase of the hype cycle, but their niche applications are expanding and may become significantly important in areas like clean energy, water purification and other processes vital for sustainable development.

Given this, it seems prudent to engage in TA to explore current issues and their implications for specific countries, sectors and professions. Simultaneously, TF should be employed to investigate longer-term concerns that require systematic and serious attention. In many cases, international cooperation will be essential to address these future challenges effectively.

2.5 Digital Transformation of Technology Assessment and Foresight

The rapid advancements in digital technologies are transforming TA/TF methodologies.[42] Digital technologies enable more sophisticated data analysis, allowing for real-time identification of emerging trends and the potential for innovative approaches to science and policy (Plekhanov *et al.*, 2018). AI, in particular, can uncover new insights by analyzing large datasets and facilitating expert judgment, which is invaluable when dealing with complex and uncertain emerging technologies.

New technologies can offer TA/TF exercises a range of possibilities to conduct activities online that have traditionally involved physical face-to-face contact. However, while online communication increases efficiency, it may hinder the development of rapport and deeper connections, which often rely on emotional as well as intellectual engagement (Benski & Fisher, 2013). Collaborative software allows for rapid collection and collation of opinions and votes. New AI tools allow for translation and transcription of speech, can rapidly summarise documents and present content in various formats and communication different styles. They also support the visualisation of ideas and narratives, and can generate simple scenarios around suggested ideas.

At present, all such applications require some human moderation, as AI systems can be prone to errors and hallucinations. Nevertheless, these new tools can considerably accelerate many elements of TA/TF, including identification of key data and literature, compilation of material reflecting different points of view, and providing provocative inputs for workshop discussion.

TA/TF practitioners are actively exploring many applications of computer-communications and AI in their work, and some consultancies are already offering "automated" trend analysis, horizon-scanning and scenario generation, and it is highly probable that such applications will soon be commonplace.

Data analytics can be used to examine key emerging issues, how they relate and where work is being undertaken. Such methods were employed in Brazilian, Japanese, Russian and South African exercises (OECD, 2018). Collective human intelligence is, of course, something that can also be supported from large-scale Delphi surveys and public consultations to the production of compelling narratives and imagery concerning potential future developments. In this way, new technologies can augment, rather than replace, more participatory approaches to TA/TF.

Behind this trend is the presence of data science experts or specialized units within or adjacent to the institutions conducting foresight activities. These units are closely integrated with foresight efforts, providing essential analytical support. Such organizational structures serve as critical infrastructure for the ongoing development of foresight. Notable examples include the Joint Research Centre (JRC)'s Text Mining & Analysis Competence Centre

TA and TF experts can balance excitement and alarm over rapidly advancing technologies' implications

Digital transformation is reshaping TA and TF, **enabling sophisticated data-driven and AI-supported methods**

New technologies can augment, rather than replace, **more participatory approaches to TA/TF**

42 Contribution from the International Telecommunication Union (ITU).

(TMA-CC),[43] the U.S. Government Accountability Office (GAO)'s Science, Technology Assessment and Analytics (STAA) team,[44] the Higher School of Economics (HSE)'s Intelligent Foresight Analytics system (iFORA)[45]and Nesta.[46]

2.6 Functional and Process Changes in TA/TF due to Rapid Technological Advancements

Real-time TA is desirable for rapid policy advice, but is challenging to achieve

Rapid technological change has implications for the conduct of TA and TF. Their own timescales may be speeded up. Grunwald (2018), for example, argues for "real-time TA", where the analysis does not wait for the technology to have emerged in order to discuss its impacts. TA can be attentive to and engaged in the design process, which is also the perspective of Responsible Research and Innovation (RRI), arguing for establishing ways of building more normative criteria into the search and design phases of innovation (Capurro *et al.*, 2015; Taebi *et al.*, 2014).

TF may be conducted with a shorter time horizon than usual, which may also make sense when the technology in question is believed to be changing rapidly. Some countries are establishing institutions specifically to meet the need for quick foresight inputs in policymaking, providing timely and effective intelligence support for crisis situations and emerging risks (Weber *et al.*, 2023).

A short-term focus may be helpful in enabling policymakers to work with targets and actions that have relatively immediate results. But one limitation of such a focus is that organizational change—and even the absorption of new technology into routine practice—may be a relatively slow process. While new generations of technology may be announced frequently, new organizational forms may take time to be developed and implemented, often with a good deal of trial and error. Real transformational change may take even longer to achieve.

Related to this, it has been suggested that adopting a relatively short time horizon in a South African TF exercise[47] may have led to more conservative expectations of change than might have been obtained otherwise. Of course, transformational change may be harder to envisage or be seen as less plausible or more threatening than incremental evolution. Over the long term, however, transformation may well be necessary for the continued viability of a socio-technical system.

A second consequence of rapid change is that it may well be important to review and refresh TA and TF exercises much sooner than would normally be the case. This is because often the social understanding of what a new technology is, and what its use implies, evolves rapidly before eventually settling into shared understandings of their design features, capabilities, limitations and prominent uses.

Substantial learning usually follows the early introduction of new technologies. They turn out to be popularly applied in ways that the original inventors and innovators had not expected (Silverstone & Hirsch, 1994). The experience of later adopters is liable to be very different from that of the pioneering early adopters (Chesbrough & Crowther, 2006; Palm, 2020). Often, but not always, the cost of the technology will fall, it will

43 For more information on the European Commission's work in text mining, visit https://knowledge4policy.ec.europa.eu/text-mining/about_en.

44 Learn about the GAO's Science, Technology Assessment, and Analytics (STAA) at https://www.gao.gov/about/careers/our-teams/STAA.

45 For details on the IFora project by the Institute for Statistical Studies and Economics of Knowledge, visit https://issek.hse.ru/en/ifora/.

46 For information on the Arloesiadur Innovation Dashboard for Wales, see Nesta's project at https://www.nesta.org.uk/project/arloesiadur-an-innovation-dashboard-for-wales/.

47 Contribution from the Government of South Africa.

become more reliable and user-friendly, dominant design features will stabilise (and sometimes a few platforms take over the landscape), and the skills and capabilities required for production and use will become more evident (Nicoletti *et al*., 2020).

Major centres of production and leading firms may be the winners of competition to be prime suppliers, though these may change over time. The routine ways in which the technologies are used, and the consequences of these, will be more apparent, including the potential of unexpected uses. Innovations in complementary technologies may be significant, and businesses may arise that provide services connected with the technology.

Such developments are often described in terms of the "industry cycle", "product life cycle" and the "technology adoption/ diffusion process" (Adner & Kapoor, 2009; Klepper, 1996; Stark, 2022). These concepts highlight that very often new technologies surprise even those who were the original innovators and early adopters. Some people argue that this can be captured in Roy Amara's Law": "We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run" (Amara, 1988), which could also be formulated as: "things at first happen more slowly than the originators expect; but their later impacts are wider than they had expected" (Brooks, 2017).

Rapid technological change creates uncertainty, including uncertainty about just how rapidly the change will manifest and affect different activities and industries. STI policies, along with other policy fields, are liable to require revision in the light of changing opportunities and new challenges. Policymakers are often underprepared to support the widespread adoption of these technologies (OECD, 2023). TA/TF cannot resolve all uncertainties, but they can provide vital information. They can point to the constellation of issues that should be taken into account, explore some alternative plausible scenarios that policies may need to be future-proofed, or designed with sufficient flexibility; and provide an improved basis for wider consultations and discussions.

Given the urgency of this work, it may well mean that initial TA/TF appraisals ideally should be made rapidly, potentially requiring greater use of digital tools. More "classic" approaches will continue to be important, not least because their pace should provide more time and occasion for reflection and deep dives into particular topics. But agile, smaller-scale and rapid exercises are liable to be vital in the context of rapid change, and their success would help build the case for ongoing work. A hybrid approach of using an agile, rapid exercise followed by a more traditional exercise may also be an option that can be pursued where appropriate.

Many countries are facing the challenge of limited awareness and capability to initiate forward-looking activities like TA and TF. This presents a strong case for international collaboration to build the necessary capacity and readiness. As far as possible, then, ways of accomplishing TA/TF more quickly and cheaply than has typically been the case in developed countries should be fostered and disseminated. Various training and awareness activities can be envisaged, along with demonstration projects and cooperative projects across sets of countries in regions where little activity has been inititiated in these fields to date.

There have been some related initiatives from such bodies as UNCTAD, UNESCO, and UNIDO, along with regional bodies, some foundations and professional networks. Currently, there is a proliferation of international and regional institutional mechanisms that can help share experiences and best practices, and assist in building TF/TA capacity where it is lacking. However, most of these initiatives are focused on specific issues and are known to relatively few potential users. None of them currently has truly global reach.

> Rapid technological change demands faster approaches to providing advice, **necessitating new institutional capacities and digital tools**

> A hybrid of rapid and classic TA/TF methods **can support both agility and deeper reflection**

> For countries new to TA/TF, international collaboration can **help build capacity and readiness**

3. TECHNOLOGY ASSESSMENT AND FORESIGHT ACROSS COUNTRIES

The adoption of TA and TF globally is rising, but they have diffused most widely among developed countries. Within countries with a tradition of using these tools, their use has been institutionalized, with diverse institutional models in place for using TF and TA. Many developing countries are completely new to these disciplines, or have done very little so far, especially with TA. International collaboration is needed to help countries with limited experience to adopt and build capacity in TF, and especially TA. United Nations agencies and other international organizations have been actively supporting developing countries in adopting and integrating these tools, especially foresight, within policymaking processes. There are also several regional initiatives on TA and TF. However, there are few, if any, initiatives with a truly global reach. Global mechanisms for international TA and TF do not actually exist yet.

3.1 Diverse Institutional Models of Technology Assessment and Foresight Across Countries

Countries implementing TA/TF initiatives are highly diverse, ranging from small island states to vast nations occupying large parts of subcontinents, from some of the world's poorest countries to those leading in GDP growth rates, and from tropical to mountainous environments. Political systems differ widely, as do cultures. In terms of TA and TF, there is huge variety in the existing capacities and the human and economic resources that could be brought to bear on these activities. The following elaboration explores the institutional forms of TA/TF across countries, highlighting decentralized and centralized models, grassroot initiatives, ecosystem-based approaches, TF hubs, public-private partnerships, governmental agencies, and parliamentary approaches, among others.

Austria offers an example of a *decentralized model of TA/TF*, involving a wide range of actors and institutions. In this model, initiating institutions like the Austrian Parliament set the agenda for TA/TF activities. Implementing bodies, such as the Austrian Institute of Technology (AIT) and the Institute for Technology Assessment (ITA), are tasked with carrying out the technical aspects of TA/TF. In addition, federal ministries may have in-house capacities that contribute to the process. Coordinating entities, such as the former Council for Research and Technology Development, play a key role in linking foresight expertise with policymaking. Educational institutions, including the National Defence Academy and the UNESCO Research and Training Centre for Future Design, contribute to building future literacy among both policymakers and the public.[48]

Singapore's Centre for Strategic Futures (CSF),[49] part of the Strategy Group in the Prime Minister's Office, represents a *centralized governmental approach*. CSF emphasizes scenario planning and promotes a "Whole-of-Government" approach to policy coherence, enhancing the nation's resilience in confronting future challenges. By linking expertise directly to national government, CSF ensures that foresight activities have a direct impact on strategic decision-making at the highest levels.

Despite facing challenges common in developing countries, such as limited resources and institutional constraints, Brazil managed to develop a strong *TA/TF ecosystem* at both the regional and national levels. The alignment of TA/TF activities across different sectors within a single institutional framework is considered best practice, addressing institutional deficiencies and serving as a strong example of effective implementation (Bakule *et al*., 2016, p. 133). The Centre for Management and Strategic Studies in STI (CGEE), established in 2001, serves as the main player in TF.[50] CGEE interacts with thousands of experts annually and undertakes regular TF activities, significantly supporting strategic decisions in Brazil's STI policy by providing intelligence services and technical support for the National Strategy in STI (ENCTI) and sectoral innovation funds. Moreover, the Observatory of STI (OCTI) focuses on monitoring the state of the art, trends, and emerging themes in the STI environment, identifying challenges and opportunities, and formulating and evaluating STI policies and programmes. The Brazilian Agricultural Research Corporation (EMBRAPA) operates Agropensa,[51] a strategic intelligence system engaging in trend analysis and horizon scanning on agriculture-related issues, often

TA and TF institutional forms are diverse, including de-centralized models, grassroots initiatives, ecosystems and public-private partnerships

48 Contribution from the Government of Austria.
49 For additional information, visit the Centre for Strategic Futures (CSF) at https://www.csf.gov.sg/.
50 For more information, visit the Centre for Strategic Studies and Management (CGEE) at https://www.cgee.org.br/.
51 For more information, visit the AgroPensa platform at https://www.embrapa.br/agropensa.

incorporating elements of both TA and TF. The Framework for Participatory Impact Assessment (FoPIA) methodology engages local stakeholders to assess the impacts of land use policies on regional sustainability and to develop sustainability guidelines, such as those concerning the expansion of the sugarcane industry. Other institutions like the National Service for Industrial Training (SENAI)[52] and the Oswaldo Cruz Foundation (Fiocruz)[53] focus on future skill requirements and health TA, respectively, illustrating a comprehensive and integrated approach to foresight across sectors.

The United States exemplifies a rich *TA/TF ecosystem*, even though the US government has not run the sort of large-scale TF programmes common in many other industrial countries. Many academic groups and consultancies perform work that closely resembles TF, and organizations such as the RAND corporation have pioneered development of relevant techniques.[54] The Future Today Institute, an advisory firm, conducts strategic foresight, enabling public and private organizations to plan for the future using the Institute's developed methodology, scenario planning, strategy advisory, and capacity building.[55] In addition to formalized approaches, there are also *grassroot initiatives*, with thorough networks like the Expert and Citizen Assessment of Science and Technology (ECAST) and the Public Interest Technology University Network (PIT-UN). These networks work to maintain and enhance the skills, knowledge, and awareness of those involved in foresight, often operating outside of formal government structures.

Russia features a *TF hub model*, exemplified by the International Research and Educational Foresight Centre of the Higher School of Economics (HSE). This Centre serves as a central hub for developing foresight methodologies and conducting futures studies. It collaborates with international organizations, research centers, and HEIs, contributing to the global foresight community. The Centre's academic impact is enhanced by its publication of the peer-reviewed journal *Foresight and STI Governance*. The Centre's work includes producing long-term foresight studies and roadmaps for various economic sectors, assisting in the formulation and revision of the Russian government strategy on Priority S&T areas and Critical Technologies, and supporting the foresight activities of the business sector. Beyond these strategic contributions, it offers specialized courses in *Foresight and Strategic Planning*, and *Corporate Foresight* to Master's students, thereby fostering a new generation of foresight practitioners equipped to navigate and shape the future.

Malaysia's approach to TF institutionalization involves *public-private partnerships*, exemplified by the Malaysian Industry-Government Group for High Technology (MIGHT), which hosts the myForesight national-level Foresight Institute.[56] Operating with substantial industry collaboration, myForesight focuses on TF and innovation, engaging in activities like roadmapping and Delphi studies. Its primary impact lies in specific industries and technologies, aiming to improve competitiveness and strengthen NIS.

TA/TF can also be *institutionalized under a specific government department*. For example, the Philippines is considering establishing an STI foresight institute

52 One example of such work is presented at https://www.oitcinterfor.org/sites/default/files/file_publicacion/oit_Prospectiva_ing_sec.pdf.

53 For more details, visit the Center for Strategic Studies (CEE) at Fiocruz at https://cee.fiocruz.br/.

54 For more information on the history of RAND, visit https://www.rand.org/about/history. RAND also operates a European Futures and Foresight Center, which can be explored at https://www.rand.org/randeurope/research/futures-and-foresight-studies.

55 Contribution from the Government of the United States of America.

56 For more information, visit MyForesight at https://www.myforesight.my/ or MIGHT's official website at https://might.org.my/.

under the Department of Science and Technology (DOST) to provide ongoing support in strategic intelligence and anticipatory governance to policymakers and civil servants. This Department has already been responsible for a TF exercise published as PAGTANAW 2050, inspired by a similar Malaysian effort. It defined the STI influences on the country's development over the coming 30 years and charted a strategic path for its scientific capital over this period. PAGTANAW 2050 was conducted with inputs from the Centre for Engaged Foresight[57]—a Philippine hub for strategic foresight established in 2012—in cooperation with the United States Agency for International Development (USAID).[58]

Chile employs a *parliamentary approach* to TF/TA through the Parliamentary Technical Advisory (ATP) of the Library of the National Congress, established in 2007. ATP conducts expert consultations using methods like the Delphi technique to address specific legislative issues, engaging extensively with the scientific community. By collaborating with national R&D agencies, universities, and international TA organizations, ATP strengthens the use of scientific evidence in legislative decision-making. Its efforts aim to democratize knowledge and contribute to sustainable development and improved quality of life.

Institutional forms of TA/TF are in constant flux, especially when countries undergo economic or political disruptions. Portugal has experienced a fluctuating, long-term process in its TF practices, with periods of activity followed by decline. This inconsistency is largely due to the fact that foresight was never deeply institutionalized in the country. It was neither explicitly nor formally embedded in the mission, laws, or bylaws of Public Administration bodies. As a result, TF was not systematically integrated into the policymaking cycle for science, technology, and innovation (STI) policy, including key areas such as planning, priority setting, programming, budgeting, monitoring and evaluation.[59]

The institutional arrangements for TA/TF across countries vary widely, reflecting different strategies to integrate TA/TF into national planning and policy. Whether through decentralized models involving multiple actors, centralized hubs, public-private partnerships, governmental agencies, or parliamentary bodies, each country tailors its approach to its unique needs and contexts, reflecting different national circumstances – both in resources and ambitions. Not all governments will be willing and able to institutionalise TA and TF in these ways, and many will still be in a position of needing to rely more on external expertise, and possibly international collaboration, while developing their national capabilities. By learning from these varied approaches, countries can refine their own TA/TF practices to better anticipate and prepare for the uncertainties of global technological change.

Institutional forms **can evolve and change over time**

Each country tailors its approach to its **unique needs and contexts, leading to diverse models**

3.2 International and Regional Initiatives in Technology Assessment and Foresight

National and subnational TA/TF activities have emerged worldwide, accompanied by international networking and the building and institutionalization of capacities to undertake and utilize TA/TF work in many regions. By pooling resources and expertise through these international partnerships, individual countries—especially developing ones—have enhanced their ability to navigate the complexities of technological change through TA/TF.

International partnerships help pool resources and expertise and **can benefit individual countries, especially developing countries**

57 For further details, visit https://engagedforesight.com/.

58 See the USAID report that outlines the aim of building a foresight-driven research agenda at https://pdf.usaid.gov/pdf_docs/PA00ZPWT.pdf.

59 Contribution from the Government of Portugal.

UNESCO has been active **in building futures awareness and literacy**

The WHO, ITU and IMO are active **in TF and TA within their respective domains**

The United Nations plays an important role in stimulating cross-border cooperation and engaging international experts to bolster TA and TF activities. Involving international experts is crucial not only for their experience but also for providing an external perspective that can build trust and credibility with local governments. This is particularly important in developing countries, where scepticism toward national experts may in practice hinder progress in building the credibility of TA/TF bodies and exercises. By facilitating collaborations that transcend national boundaries, the UN can help build national capacity with the aim of helping developing countries harness these tools to ensure that technological advancements contribute positively to their sustainable development.

One notable initiative under the UN umbrella is the UNESCO Chairs in Future Studies programme. Developed over several years, this programme aims to raise awareness and foster both public and scholarly interest in future studies, particularly in developing countries. With over 50 chairs established worldwide, the initiative serves as a valuable platform for capacity building. However, challenges persist due to a lack of standardized methodologies across the chairs, leading to inconsistencies in approaches and outcomes. Additionally, not all chairs maintain a focus on STI, which can limit their direct impact on TA and TF. Despite these challenges, the programme's success in promoting "futures literacy" presents an opportunity to enhance efforts in TA and TF by leveraging this foundational interest and expertise.

Further exemplifying UNESCO work on TF is the Global Futures Literacy Network. This diverse network comprises futures researchers, practitioners, and supporters, including UNESCO Chairs in Futures Studies and members of the High-Level Committee on Programmes (HLCP) Foresight Network. Spanning academic and government institutions, businesses, and non-governmental organizations globally, the network aims to share design practices, resources, ongoing projects, and progress updates. By facilitating the exchange of knowledge and best practices, it enhances the capacity of its members to engage in effective TF activities.

Beyond UNESCO, other UN agencies play critical roles in advancing TF and TA within their respective domains. Organizations like the World Health Organization (WHO) conduct health technology assessments (HTA) and engage in horizon scanning and pandemic preparedness initiatives. Similarly, the International Telecommunication Union (ITU)[60] and the International Maritime Organization (IMO)[61] address technological and environmental issues pertinent to their respective fields.

These sector-specific bodies ensure that foresight activities are tailored to the unique challenges and opportunities within different technological domains. For example, the ITU's Focus Group on Technologies for Network 2030 brought together over 200 experts from 50 organizations to anticipate future network technologies. The United Nations Development Programme (UNDP)[62] works with many developing countries (e.g., Belize) to support the integration of foresight into national policymaking processes through its country programs and build foresight capacities and futures literacy.[63] Moreover, the United Nations Industrial Development Organization (UNIDO) implements

60 ITU provides Strategic Foresight 101 course to participants from various sectors on the future of digital technologies. For more information, visit https://academy.itu.int/training-courses/full-catalogue/strategic-foresight-101.

61 For more information, see IMO Technical feasibility assessment on shipping decarbonization, available at https://www.imo.org/en/MediaCentre/Pages/WhatsNew-1868.aspx.

62 In 2022, UNDP published Foresight Playbook: An Overview of Foresight Tools, https://www.undp.org/asia-pacific/publications/undp-rbap-foresight-playbook.

63 Contribution from the Government of Belize.

global and regional TF initiatives to build capabilities in anticipatory governance of emerging and critical technologies, and was particularly active in capacity building in foresight two decades ago.

In 2021, United Nations Conference on Trade and Development (UNCTAD) launched a pilot project titled “Technology Assessment in the Energy and Agricultural Sectors in Africa to Accelerate Progress on Science, Technology, and Innovation” with three national pilot initiatives in Seychelles, South Africa and Zambia[64] (UNCTAD, 2024a, 2024d, 2024b).[65] The project advocated a participatory approach to TA by incorporating citizen and decision-maker participation along with expert input during the process. This would help to open up national discussions about the implications of technological change, moving beyond narrow technical or accounting exercises to assess the socio-economic and environmental implications of adopting a technology that is new or relatively new to the country. Based on national discussions, each of the three countries selected a technology for assessment. Seychelles chose agrivoltaics for controlled-environment crop production (combining agricultural and renewable energy technology), Zambia focused on biogas (renewable energy) and South Africa selected electrolysers for green hydrogen production (also renewable energy).

The UNCTAD project designed and deployed a structured methodology for assessing the socio-economic and environmental implications of technologies for SDG-relevant challenges. Adapting methodologies used in developed countries for deployment in developing countries, it used a seven-step approach (Figure 1).

These steps include establishing governance structures (a steering committee and an expert group), identifying a specific technology to assess, mapping stakeholders to participate in the assessment, and gathering both qualitative and quantitative data from the stakeholders.

The UNCTAD project sought to encourage a participatory process involving a wide range of relevant stakeholders. It also included consideration of specific impacts of technology adoption on women, youth and marginalized groups. The methodology, designed to provide guidance to developing countries in undertaking a technology assessment, was revised based on the experience of the project and is available online for use by interested developing countries (UNCTAD, 2024e).[66] The goals of the project were to build national capacities for conducting TA, develop a bespoke methodology for undertaking TA in a developing country for use in the three pilot TA exercises, generate policy recommendations for relevant national authorities, and help the pilot countries enhance their capacity to use TA to harness the benefits of a technology while mitigating their potential negative effects.

In addition to TA/TF projects led by international organizations, various regional initiatives have been established over the past few decades to advance TF across different parts of the world. These initiatives aim to build capacities, foster collaboration, and integrate foresight activities into strategic planning to support SDGs.

The Ibero-American Futurists Network (RIBER) connected TF activities in Latin American countries with Portugal and Spain under the Millennium Project.[67]

The UNDP and UNIDO have worked **on integrating foresight into country planning and building capacity**

UNCTAD piloted a project **to introduce participatory TA in African countries with a bespoke methodology**

Regional initiatives advance **foresight, build capacity and support SDG-aligned strategic planning**

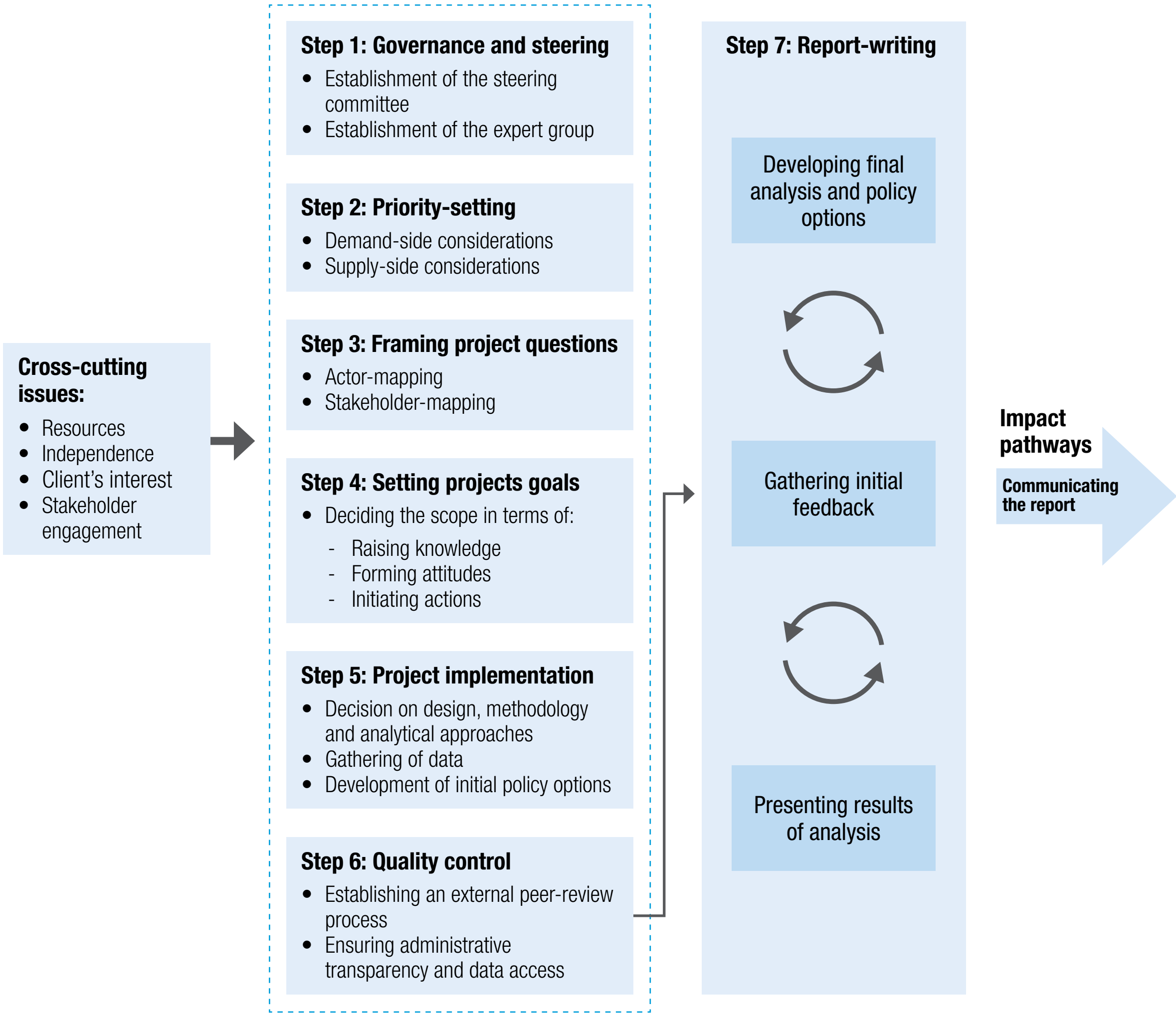
64 Contribution from the Government of Zambia.

65 The project responded to the ECOSOC Resolution on Science, Technology and Innovation for Development E/RES/2018/29, encouraging countries to undertake TA exercises as a process for structured debates around new technologies, while also encouraging the CSTD and UNCTAD to explore the feasibility of such exercises.

66 Available at https://unctad.org/publication/technology-assessment-developing-countries-updated-proposed-methodology.

67 More information on the Millenium project is available via this link https://www.millennium-project.org/.

Figure 1
Seven Steps of the UNCTAD TA Methodology for Developing Countries



Source: UNCTAD (2024e).

The network promoted best practices in Delphi studies and scenario planning that have strengthened foresight and TA capacities across the region, equipping member nations to better anticipate and plan for technological and social shifts.

In Southeast Asia, the ASEAN Foresight Alliance (AFA)[68] facilitated evidence-based future planning to support national policy and strategy development within ASEAN countries, with a particular focus on environmental sustainability. Recently, AFA submitted its inaugural report on foresight for the ASEAN STI Ecosystem to the ASEAN Committee on Science, Technology, and Innovation (COSTI). This alliance also seeks partnerships with private-sector and international organizations to advocate for its findings and drive further progress.[69]

68 For more details, refer to the ASEAN Foresight Alliance (AFA) at https://www.akademisains.gov.my/ar22/asean-foresight-alliance-afa/.

69 Contribution from the Government of the Philippines.

The Asia Pacific Futures Network (APFN) promotes Futures Thinking across the Asia-Pacific region, while the APEC Centre for Technology Foresight (CTF),[70] established in 1999 with support from the Thai government, provides foresight services and workshops on key emerging topics like net-zero emissions and the circular economy (Cruz & Moura, 2023).

The BRICS nations have also shown a strong demand for building national TA/TF capabilities. These countries are actively leveraging established frameworks to support skills development and collaboration across developing regions. For example, the South African National Research and Technology Foresight project partnered with another BRICS country. In addition to local stakeholder interviews and workshops, comprehensive big data analyses were conducted by Russian scholars from the Higher School of Economics, providing valuable insights to support TF in South Africa.

The European Parliamentary Technology Assessment Network (EPTA) exemplifies one of the most comprehensive international initiatives dedicated to TA. EPTA supports policymakers in understanding the potential social, economic, and environmental impacts of technologies, thereby contributing to more informed decision-making across Europe. One of EPTA's key contributions is the promotion of common TA methodologies and frameworks, which have helped standardize approaches across countries and regions. This standardization allows for more effective sharing of knowledge and results, as well as the development of comparative studies that illuminate the impacts of technologies across the continent.

At the global level, there are few, if any, initiatives with real global reach. There is a Global Technology Assessment Network (GTAN) that was established in 2019 with the aim to concretely develop cooperation among researchers and institutions and to establish long-term working structures for a global TA, including facilitating global cooperation on TA. The network has over 30 members from countries across the globe but is not yet truly global in its reach, and its activities are so far limited in nature. Global mechanisms for TA and TF do not exist yet but would be useful to provide support to countries on TA and TF globally.

By sharing knowledge, methodologies, and best practices, international organizations and regional TA/TF networks significantly enhance the capacities of nations—particularly developing ones—to navigate technological changes effectively. As technological advancements accelerate and grow increasingly complex, these partnerships will be crucial in ensuring that progress is inclusive and that all members of the global community can benefit equitably from technological innovation.

There are no truly global TA/TF initiatives **but global mechanisms could play a useful role**

International collaboration is vital for building capacities for TA and TF, especially in developing countries

70 For more information, visit https://www.asiapacificfutures.net/.

4. OVERCOMING CONSTRAINTS IN TECHNOLOGY ASSESSMENT AND FORESIGHT

Implementing successful TA and TF exercises is not easy, and there can be many challenges. The main challenges include limited human and financial resources, weak institutional frameworks and futures literacy, as well as poor integration into policy processes. The linkages to policy and the impact of exercises is often not clearly evaluated, although there are examples where they have had significant policy impact. There are additional challenges that may affect specific countries and exercises, such as the high cost of access to databases. Based on country experiences, the success of exercises depends in part upon effective institutionalization in the country, the existence of political support, investment in building the relevant skills required, and adequate stakeholder engagement. Among stakeholders, other than scientists and other technical experts, it is particularly important to engage policymakers, the private sector and key non expert societal stakeholders likely to be affected (including potentially marginalized social groups such as women and youth, among others).

4.1 Challenges in Implementing Technology Assessment and Foresight

In many developing countries, one of the most fundamental challenges in implementing effective TA/TF activities is the scarcity of financial and human resources.[71] This limitation severely hampers the ability of nations to conduct comprehensive TA/TF exercises, leading to insights that may lack depth and comprehensiveness. The shortage of resources affects every stage of the TA/TF process, from gathering relevant data to analyzing trends and projecting future scenarios.[72] This deficiency means that decision-makers in these countries are often working with incomplete information, which can undermine the strategic value of TA/TF in shaping long-term policies and initiatives.

In addition to resource constraints, there is a significant issue related to limited TA/TF capacity within public administration. This challenge is primarily due to a lack of trained personnel skilled in TA/TF methodologies, together with the absence of robust institutional frameworks to support ongoing TA/TF initiatives. Without a dedicated and knowledgeable workforce, these countries struggle to integrate TA/TF exercises into their policy-making processes effectively. There is a weak science-policy interface in many countries irrespective of their level of development that is more generalized, going beyond TA and TF. This disconnect between TA/TF and practical application leads to a situation where even the most well-conceived strategic intelligence activities fail to influence policy decisions, thus reducing their overall impact. Improving this interface is important to increase the usefulness of TA and TF exercises in informing and influencing policy decisions.

To address this, it is essential to better tailor TA/TF exercises to meet the specific needs of decision-makers and stakeholders, while also enhancing understanding of the capabilities and limitations of these approaches. A key challenge is determining at which stages and to what extent relevant stakeholders should be involved through participatory methods, all while ensuring that the processes remain lean and relevant.[73]

Moreover, both in developed and developing countries, there is an underdeveloped futures literacy within both the public and private sectors. Even in countries where some TA/TF activities are taking place, the broader understanding of what they entail, and why they are important, is often lacking. This can lead to limited engagement from critical stakeholders, which in turn diminishes the effectiveness of TA/TF exercises. It is often a challenge to engage high-level policymakers and the private sector in these exercises. When key players do not fully comprehend or value the TA/TF process, it becomes challenging to secure the necessary support and participation, which in turn hinders the generation of meaningful and actionable insights.

Another significant challenge is the unclear or inconsistent uptake of TA/TF results by political decision-makers. Even when TA/TF activities are successfully conducted and generate valuable recommendations, there is no guarantee that these insights will be utilized in policy-making processes. This lack of integration between TA/TF results and political decision-making can significantly diminish the potential impact of TA/TF activities, as valuable insights may be overlooked or ignored.

Building this linkage is critical but there is no easily applicable blueprint for how to do it. Involving key policy people at opportune

Scarce financial and human resources are a fundamental challenge limiting adoption in developing countries

A weak science-policy interface is endemic across many countries irrespective of their level of development

The uptake of TA/TF results by **decision-makers represents a critical challenge**

71 Contribution from the United Nations Technology Bank for Least Developed Countries (UNTBLDC).
72 Contribution from the Government of Oman.
73 Contribution from the Government of Germany.

High costs of accessing research databases **limit effective TA and TF in developing countries**

Private sector engagement is typically deficient as these exercises are not revenue generating activities

points or communicating regularly with them on results during a TA or TF exercise may help. Countries new to TA and TF might seek ways to establish linkages from the outset when adopting these tools. In one recent example, the UNCTAD methodology for its pilot project on TA in African countries recommended the establishment of a Steering Committee to help connect with high-level officials and policymakers. In practice, however, the success achieved in this regard was only partial. Countries may face constraints such as limited resources, time, or institutional capacity, which can undermine the potential effectiveness of such a committee (UNCTAD, 2024e).

Access to research outputs and bibliographic databases presents a critical challenge in many developing countries.[74] The high costs associated with accessing these essential resources limit the ability to conduct thorough and effective TA/TF exercises. This lack of access is particularly problematic in developing countries, where financial constraints are already a significant barrier. For instance, Iran and Cuba face considerable difficulties in accessing the data necessary to evaluate technological developments, while Indonesia struggles with a lack of data on industry needs, research outputs, and related activities. Without reliable access to such data, developing countries are at a disadvantage in making informed decisions about future technological and economic developments. Available statistics required for TA/TF need to be created, and new types of data and data analysis should be accessed.

Adopting a purely sectoral approach to TA/ TF activities, where the focus is narrowly on specific industries or technologies, can limit the broader applicability of TA/ TF results.[75] This approach can prevent the identification of cross-sectoral issues and opportunities that could be crucial for a more holistic understanding of future trends and challenges. By focusing too narrowly, countries may miss out on important insights that could benefit multiple sectors, thereby limiting the strategic value of their TA/TF activities.

Engaging the private sector in TA/TF activities remains a significant challenge in many cases. Without active participation from industry stakeholders, TA/TF exercises risk missing out on critical insights related to market needs and trends. In some cases, private sector companies may represent an essential or perhaps the main source in a country of specialized expertise on a particular technology. This lack of engagement can lead to TA/TF activities that are disconnected from the practical realities of the market, reducing their effectiveness and relevance to policy-making and strategic planning.

In many developing countries, there is a lack of interest or motivation among potential respondents to participate in TA/ TF exercises, such as Delphi surveys.[76] For example, private sector companies may face commercial reasons for declining invitations to participate in such exercises, as it is not directly a revenue-generating activity. This lack of engagement can result in biased or incomplete data, which undermines the validity of the TA/TF conclusions. When key stakeholders are not invested in the TA/TF process, the quality of the insights generated is compromised, making it difficult to rely on these results for strategic decision-making.

It is also noteworthy that documentation of TA/ TF efforts in developing countries is often sparse, especially when it comes to assessing their tangible impact on policy and planning. Recommendations from TA/TF exercises are frequently just one component within a broader set of proposals emerging simultaneously. A notable exception is Colombia's Technology Foresight Programme (CTFP), which stands out for

74 Contribution from the United Nations Industrial Development Organization (UNIDO).
75 Contribution from the Government of Cuba.
76 Contribution from the Government of the Islamic Republic of Iran.

incorporating a systematic evaluation of its TF activities—a practice not very common in similar efforts (Popper *et al*., 2010).

In many cases, the priorities of TA/TF initiatives are driven more by prevailing trends and external agendas than by locally grounded needs assessments. There has also been a weak performance on the evaluation of the impact of foresight and TA exercises. Without systematic follow-up to evaluate the actual impact of TA/TF initiatives, valuable opportunities to capture lessons learned and improve future efforts are lost. This is likely to represent a more generalized feature of STI and development policy more broadly that extends beyond TA/TF exercises.

The success of TA/TF activities is closely tied to political will, as seen in countries like Indonesia and Cuba. In Indonesia, for example, TF has not yet been prioritized within the national research and innovation ecosystem, making it difficult to use these insights as a basis for policy formulation.[77] Similarly, in Cuba, challenges related to the early identification of obsolete or unsustainable technologies are compounded by issues of technology transfer management. Without strong political support, TA/TF initiatives struggle to gain the traction needed to influence national policies and strategies effectively.

The political culture in many countries may create a focus more on the short to medium term, with governance organized around national development planning periods of five years. In those cases, there could be less of a tradition on longer-term planning with time horizons often adopted in TF exercises. Introducing TF methodologies in these contexts could encourage policymakers to adopt a broader, longer-term perspective, fostering a cultural shift towards extending planning horizons.

Managing clients' and customers' expectations is another challenge, as noted by the Philippines.[78] Ensuring that the outcomes of TA/TF activities align with the needs and constraints of stakeholders, such as government agencies or private sector clients, is critical for the success of these initiatives. When expectations are not managed effectively, there is a risk of misalignment between the TA/TF results and the practical needs of those who rely on these insights for decision-making.

Linking TA/TF with the formal planning process is crucial. Without this linkage, the strategic insights gained from TA/TF exercises may not translate into actionable strategies and policies. This disconnect can reduce the effectiveness of TA/TF in shaping long-term national development plans and hinder the ability of governments to respond proactively to future challenges and opportunities.

Additionally, emerging technologies often outpace existing legal frameworks, which might complicate processes for integrating new solutions into established systems. The gaps between technological innovation and regulatory frameworks may slow down the adoption of new technologies and reduce the effectiveness of TA/TF activities.

Finally, the early identification and management of obsolete technologies is a crucial yet complex and resource-intensive task. Maintaining technological relevance and sustainability requires significant TA/TF capacity, which may not always be available. This challenge is exacerbated by the need to continuously monitor technological developments and assess their long-term viability, a process that demands both financial resources and specialized expertise. Without the ability to identify and phase out obsolete technologies, countries risk falling behind in the rapidly evolving global technological landscape, which can have significant economic and social implications.

Evaluation of impact of exercises on policy and planning **is often inadequate**

Political will and leadership make a big difference with TA/TF success and impact

Linking TA and TF to formal planning **is crucial to turn insights into policy action**

77 Contribution from the Government of Indonesia.
78 Contribution from the Government of the Philippines.

4.2 Learning from Countries' Experiences

Institutionalizing TA and TF within a country **is necessary to generate strong impact**

In countries with significant TA/TF experience, typically high or middle-income countries, a specific organization is often established to undertake these activities and feed them into the policymaking process. TA/TF then benefit from being institutionalized in some form within the country. Ideally, this organization operates with a clear legal mandate, which enhances its authority and effectiveness. Both TA and TF are frequently conducted by the same body, although this is not always the case.

These initiatives often stem from policymakers recognizing the need for a systemic approach to the NIS. However, this need is more commonly framed in terms of TF supporting priority-setting and addressing new technology development opportunities and challenges associated with sustainable development, rather than pursuing the ambitious goal of fully integrating or "wiring up" the NIS.

Support from policymakers **is also critical for success and sustained activity**

This likely reflects a realistic assessment that reconfiguring such a complex system will require ongoing, ambitious policy development and implementation. While TA and TF can inform and support this process, much of the momentum will come from other sources. To the extent that what some commentators refer to as a 'foresight ecosystem' has been developed (Monteiro & Dal Borgo, 2023; School of International Futures, 2021), many industries and scholars are now more or less routinely engaging in anticipatory analysis, drawing on inputs from various institutions capable of applying TA and TF methods when needed.

TA and TF institutions should engage business, academia, and civil society to bridge science-society gaps

Such a system requires sustained support from policymakers, and several of the cases described have been long-standing, indicating they have continued to garner adequate political backing. However, this ongoing support may be threatened by the need to allocate resources to immediate crises and pressing issues, or by the rise of social movements that challenge the necessity of systematic and scientific analyses, or contest established understanding by a majority of experts on issues like climate change.

The COVID-19 pandemic is a case where many STI institutions refocussed their attention on national efforts to address this crisis, but where anti-science opinions gained considerable ground in several countries. Addressing this challenge requires scientists to engage beyond academic circles ("ivory towers"), effectively communicating the value of their work and countering public scepticism. Policymakers should bolster education and research funding, ensure easy public access to the results of publicly funded research for free, and consider how to address the precarious employment conditions often found in academia. To restore public trust, the scientific community must also tackle internal issues: enhancing support for trainees and students, addressing systemic biases, and creating transparent, timely correction processes within the governance of research institutions.

Given the existing gaps between science and the public, TA and TF institutions might seek to provide support to, and gain backing from, other segments of society, including business, academic, and civil society organisations. One function that both can play, which is helpful to many stakeholders in developing countries, is to provide evidence-informed reports on global technology developments.

The TA and TF activities are typically carried out using a range of complementary methods and techniques, which inevitably requires the availability of individuals with the ability to apply these techniques and to assess the quality of work undertaken by others. Typically, these capabilities have been fostered in the first instance by sending staff members for training overseas, although learning-by-doing with the support of external consultants and international collaboration is also common. Once skills are established there may be some adaptation of methods to local environments, but it is also common for practitioners to remain in contact with their peers in other countries, for example by participating in international conferences and the like.

Where there is limited familiarity with the purposes and practices of TA and TF, it may be premature to create an institution that is expected to undertake these activities on an ongoing basis. An initial project may prove to be an appropriate starting point for developing capabilities and experimenting with procedures. Some activities can be carried out with management from within a key government ministry, department or agency though it will not be enough to delegate oversight or management responsibility for them to an untrained and unsupported member of the public sector.

It will be critical for a senior figure to be a "product champion" of TA/TF—someone prepared to defend the activity, mobilise engagement from members of that ministry and other parts of government, and ensure that results are adequately disseminated and acted upon. This will also mean that the scoping of the project specifies what sorts of processes and outputs are needed in order to attain this policy impact, and what sorts of stakeholders must be engaged. The product champion will almost certainly need to be someone that is respected, or can build respect, across a range of stakeholder communities, including academia, civil society and the private sector.

In terms of securing policy impact, the STI agenda may be reaching a critical point, with the need for policies to address specific technologies or technology choices, or to set the course for the application of STI to sustainable development. TA/TF work can feed into the development of these policies, but it will need to be timely and evidence based. Timeliness may be particularly problematic, since decision-makers may require results within very short timeframes. This urgency can create strain, especially for academic researchers who typically conduct studies over extended periods. In such cases, the challenge lies not just in maintaining motivation, but in achieving the necessary depth and quality in urgent reports to meet the high standards that TA/TF exercises aim for. Researchers may need to shift from presenting comprehensive scientific findings to offering expert opinions based on less complete information. However, the focus should remain on ensuring quality, avoiding superficiality, and maintaining thoroughness, even when time is limited.

Evaluation of the success of activities seems relatively underdeveloped, and undertaking independent evaluations could offer significant lessons for practitioners. The continuation of institutions and their programmes demonstrates that senior policymakers consider their work well worth ongoing support. The technical quality of work can be assessed by expert peers, which may require reaching out to global TA and TF communities. But more documentation of policy impacts, and lack of impacts in some policy areas and communities, could be informative. It is not unknown for policy formulation and implementation to diverge in crucial respects from the recommendations that they are supposedly based upon.

Building capacity through skills development is important to localize and sustain efforts over time

Creating product champions **promotes success in undertaking TA and TF exercises**

Evaluation practice **should be improved to promote learning**

5. RECOMMENDATIONS

This chapter presents key insights drawn from the research, discussions and materials developed for this report. It begins by offering practical guidance on how to organize TA and TF exercises, particularly aimed at countries with limited experience. It then outlines tailored recommendations for policymakers, TA and TF practitioners, and international organizations. These recommendations aim to provide actionable policy advice and highlight how international collaboration can support the wider diffusion of these tools. The ultimate goal is to enable all countries to leverage TA and TF to generate strategic intelligence for policymakers, build national capacities for anticipatory technology governance, and strengthen strategic planning for STI policy as well as broader development policy.

5.1 Organizational Issues

Country Level

How are TA and TF best organised? There is no one-size-fits-all answer to this, and it may well be that some experimentation is required where local experience in these fields is limited. For example, in some countries, TF activities are authorized by legislatures, while in others, they are authorized by the executive branch. This institutional difference means that TF and TA are archived and managed in separate organizational structures, potentially making integration between them challenging.

There are three main decisions involved: (1) the scope of the work; (2) the location of the work; and (3) the span of the work.

Scope of the work

Is this envisaged as a one-off activity or as ongoing work?

One-off activity

The scope of work in this context can be envisioned in several ways, depending on the needs and objectives at hand. One possibility is that the work is intended as a *one-off activity*. Often, issues arise where rapid policy response is needed, or at least where policymakers need to be briefed about whether technological matters require such a response. TA/TF can work as a reference point in that case, organised as a government unit, for example.

Many TA institutions are able to prepare rapid briefings about new developments, and will routinely conduct horizon-scanning to identify future and emerging policy issues. When additional expertise is necessary, these units can recruit external specialists to provide the required information and advice, ensuring these units are well-informed about where and how to access such expertise. It may be possible to draw on work conducted in other countries, where TA teams may well have addressed similar demands. Especially for small countries with little experience, collaboration with other countries (e.g., sub-regional or regional neighbours sharing common challenges) may present an attractive possibility.

Another scenario where government involvement might be required is in the context of creating or renewing national plans in specific areas. This may be specifically related to STI, but it could also be related to any field or set of issues where STI developments have substantial implications. Sustainable development and climate change policies are evident cases, but so are, for example, long-term health policies, which necessarily need to consider technological trajectories as well as demographics. Many of the early TF programmes in the 1990s and shortly after were commissioned without any original intentions for ongoing work. In several cases, it was assumed that results would simply feed into an STI plan designed to guide development for at least a decade.

Ongoing activity

Alternatively, a more sustained approach involves establishing a permanent unit within the government or an external centre of excellence that does more than respond to government requests. Such a unit would take a proactive role in shaping its agenda. This is likely to involve some combination of ongoing assessment of the technology landscape, along with “deep dives” into specific technological challenges or policy areas where STI is liable to play a large role.

Some domains may require ongoing activity, especially the more immediate and recurrent challenges associated with health TA and the types of impact assessment required by Ministries of the Environment and similar bodies. Responsible entities must be able to undertake or commission such appraisals, and to be able to act on their findings.

Location of the work

(How far) is it to be carried out internally or externally?

Externally

When the government has little experience with TA/TF work, then it can make sense to employ external expertise, including from other countries if necessary. If external contractors are engaged to lead specific projects, there must at least be internal capacity to oversee their work and ensure its alignment with policymaking. More may be gained by associating national staff members to work with and learn from the consultants, thus developing local capabilities as part of the effort.

Internally

An internal team should have prior training or experience in applying TA/TF methods, access to appropriate facilities to conduct the exercises themselves, and establish a programme

There is no one-size-fits-all model for organizing TA and TF, local experimentation is essential

Blending internal teams with external experts **can build national TA and TF capabilities over time**

of work if the activity proves helpful to policymakers or policymaking processes.

Hybrid strategy

In a well-resourced setting, it may be appropriate to combine both approaches. For example, in the UK Foresight Programme during the early decades of this century, a government-based unit appointed external parties to lead specific projects. Consultant groups might prepare methodological guides, while senior academics or industry figures could lead projects examining specific topics. The expertise or reputation of the leader in such cases can help with recruitment of participants and achievement of results.

Regardless of the type of team responsible for executing the projects or program of work, the government must ensure it has sufficient "*absorption capacity*" to benefit fully from learning the methodology implemented. This capacity to absorb knowledge is crucial for integrating TA/TF results into policy formulation effectively, ensuring that these insights are both relevant and adequately considered. Additionally, the government needs to be capable of asking the right questions to guide these assessments.

When TA is mainly undertaken as a service for Parliaments and Parliamentary Committees, a clear liaison point with the implementing unit is necessary. TF, in contrast, may require an office under a specific ministry (while liaising with others), or reporting to the head of state or the senior decision-making body, or to the most senior STI official, if such a position exists.

Span of the work

How far is the activity more TA-like, focusing on short-term issues and responses, or TF-like, addressing long-term challenges and opportunities?

Ideally, both are to be undertaken, but circumstances (and especially crises) will affect the urgency with which each is set in motion. Given the recurrent need of policymakers to have rapid advice on emerging technology-related issues, it is crucial to have timely access to an institution or network capable of providing reliable evidence.

The question can be posed in another way: how far should there be a division of labour between groups working on shorter- and longer-terms? TA and TF functions are often both undertaken. In some Western countries a similar state of affairs persists, while in others there are different institutions: TA bodies giving parliamentarians immediate advice (mostly on shorter-term issues), and TF units focus on informing strategic policymaking.

Some commentators talk of the national "ecosystem of foresight" (School of International Futures, 2021), though the idea is applicable to both TA and TF. In essence, this notion involves skills and knowledge about these approaches being distributed in various locations around the country, such as HEIs, research institutions, and consultancies, as well as in various parts of government and the civil service. Consequently, different ministries, not just the main department concerned with STI, along with the parliament or equivalent bodies, possess and organize relevant skills and knowledge.

International Level

International organizations have often played a positive role in moving TA/TF practices forward across countries, with training programmes, handbooks and practical guides, and funding and other support for national projects. Bodies such as the EU, UNIDO, UNDP, UNCTAD, and the OECD have made several efforts to establish networks for the exchange of experiences among practitioners (and sometimes users) from different countries.[79] Many countries receive considerable support from the United Nations and other international bodies in their TA/TF activities,[80] and they have learnt from good practice elsewhere.

While such international collaboration is valuable, it often appears to be somewhat ad hoc or opportunistic. It may be timely to consider the establishment of global platforms aimed at raising the overall standard of TA/TF and supporting countries that are beginning to engage in these activities, especially those starting from a limited base. For instance, there is currently little documentation available on how projects are evaluated or what their long-term outcomes have been.

Global support mechanisms could provide the following types of support:

- Training courses of various durations, aimed at potential users and/or practitioners of TA/TF, and ranging from basic awareness-raising to in-depth development of skills in specific tools and techniques.
- Internships and placements that could be in official agencies, consultancies, relevant research institutes and university groups that would provide direct experience of ongoing projects.
- Supporting regional networks of experts and joint projects across countries in developing regions.
- Access to expensive data and/or support with sophisticated data analytics. Sharing of results that are liable to be of common interest, e.g., horizon-scanning and megatrend analysis.
- Sharing methodologies and possibly developing international methodologies.
- Compilation of accounts of good practice, including ways of achieving diverse and inclusive participation, of rendering technical output suitable for less technical audiences, etc. Encouraging policymakers and TA/TF practitioners to learn from good practice, and to share their experiences of attempting to apply it in specific contexts and to specific topics.
- Exploration of culturally relevant approaches (potentially using indigenous knowledge) for different contexts.
- Working with existing networks that bring together practitioners of TA/TF and related topics—not only more limited impact assessments and health TA, but also fields such as risk assessment, disaster preparedness and management.

International organizations help advance TA and TF **through training, guidance and national project support**

5.2 Practical Issues

The discussion below provides a range of recommendations addressed to policymakers, TA and TF practitioners and international organisations, which can be important players in helping with capacity building on TA and TF and other support. A few general points can be made before going into details.

While it is possible to provide some indication of the relative importance of different recommendations, it must be stressed that actions will necessarily be very context-specific. For example, engagement with international initiatives in TA or TF will depend upon the existence of such initiatives and on the willingness of their coordinators to engage with your country.

79 At the beginning of this century, the European Commission funded and published a series of "Practical Guides" for Foresight at the regional level, in the national language of each member state. These were Q&A guides, outlining rationales, issues and methods, with each having its own section on local resources. See https://op.europa.eu/en/publication-detail/-/publication/e6c42e9c-100a-4bf7-95c6-5bce0caf72f5.

80 See UNDP (2018) Foresight Manual Empowered Futures for the 2030 Agenda, available at https://www.undp.org/sites/g/files/zskgke326/files/publications/UNDP_ForesightManual_2018.pdf. UNIDO (2005) Technology Foresight Manual, available at https://downloads.unido.org/ot/47/88/4788327/20001-_23148.PDF.

TA and TF are most effective when co-produced through close collaboration between policymakers and practitioners

The relations between policymakers and practitioners are important for the results of TA and TF to inform and shape policies. It is rarely a simple, arm's-length transaction, where all that happens is that the policy client specifies the sort of project they require, practitioner fulfils this brief, and the client then acts upon the results. Instead, this process is more accurately described as *co-production*.

Interaction between the client and practitioner during the scoping phase can significantly benefit the project by clarifying the exact problem to be addressed, identifying which stakeholders to involve, determining the appropriate methods to employ, and understanding the broader policy agenda the work supports. TA institutions can also be independent enough not to follow any specific political agenda (as is the case in Switzerland) yet still enrich their ongoing processes through exchanges with policymakers.

Often, changing circumstances may lead to rethinking the policy context, reassessing the appropriate stakeholders, and redefining the scope for collaboration. Close interaction between client and practitioner can facilitate flexible adaptation to these evolving demands.

Independent, cross-sectoral TA/TF centres **are vital to inform policy, integrate expertise and encourage collaboration**

At least one project champion is required both in the client and in the institutions supplying the TA/TF services. Some senior members of the client organization should actively participate in project meetings, learning about the issues that will become objects of policy and to learn about other stakeholders whose engagement may be crucial to policy success. It has been often remarked that the outcome of successful TF is as much about gaining from participation as it is from clearly laying out the process outputs through reports, priority lists, and similar documents. These participants can also carry the messages of the TA or TF process, along with the work and thinking that underpin the results, into their organizations. In addition to the specific focus of the exercise, they should also learn about how and when TA/TF can be applied effectively in their areas of work.

Close interaction is also extremely helpful in determining the ways in which outputs are formulated, presented, and disseminated. All of these can be important determinants of the eventual impact of the work. Finally, there is a danger that the assumption will prevail that TA and TF work is someone else's business, and that since there are specialists elsewhere undertaking such work, it can be left to them. Spreading a culture of STI assessment and foresight across government, and society more widely, is the best guarantee of better-informed policymaking in a country.

5.3 Recommendations for Policymakers

Organizational Issues

Establish or enhance TA/TF centres: If centres dedicated to TA/TF do not yet exist, initiate the formation of a team to scope potential projects that will inform upcoming STI-related decisions. Scoping should be treated as a critical task. It will determine much about how the project is conducted. Decisions to consider here include: what the immediate topic of study is (and how it is framed in terms of, for example, regional or gender issues, time horizon, national goals); how the project is to be managed and governed (e.g., who is to belong to a steering committee, and what sort of monitoring of progress is undertaken); whom it will report to, on what timescale).

Develop a preliminary roadmap: The initial scoping should lead to a preliminary roadmap outlining the project's key activities, timeline, and immediate outputs. This roadmap should serve as a foundation for a more detailed plan, which will be developed in collaboration with the project leadership to ensure clarity and alignment with broader policy goals.

Appoint or identify project champions: To ensure the success of the initiative, appoint or continue to nurture project champions who can advocate for and support the work. It may be beneficial to delay addressing certain topics until an appropriate champion is identified. Additionally, an overarching program champion should be designated to oversee ongoing TA or TF activities, fostering collaboration across government departments and ensuring that policy-relevant outcomes are effectively implemented.

Encourage active engagement from relevant government departments: Actively involve members of government departments where the project results are likely to have the most impact. Their engagement is crucial, not just as representatives of their departments, but as experts contributing their specialized knowledge. They can offer insights on how the project outcomes might align with departmental timelines, suggest appropriate terminology and leverage points, and identify ongoing actions that could either complement or conflict with the project's goals. Moreover, they can help frame the project outputs in ways that are meaningful and actionable for policy actors.

To maximize their contribution, it may be necessary to provide basic training in TA/TF principles, methodologies, and rationales. This training will enhance their "absorption capacity," enabling them to fully grasp the significance of the project results and effectively communicate key insights to others within their departments.

Ensure and safeguard the independence of TA/TF teams: It is crucial to maintain the independence of the TA/TF teams, even if their results are pointing to flaws in policy processes and decisions. TA cannot be rubberstamping existing choices (impact assessment may determine their costs and benefits). TF cannot be rubberstamping existing lists of priorities or concluding that current policy actions are sufficient to achieve their purposes when evidence indicates otherwise.

Facilitate participatory TA/TF with caution: While participatory approaches have been successful in countries with a strong civil society, they can be challenging in contexts with high levels of social or political polarization. Some STI issues are highly controversial, with recent years seeing arguments about AI and GMOs join longstanding debates about, for example, nuclear power, polluting technologies and animal experimentation. Participatory approaches do not mean treating all opinions as of equal value, but where practicable, they may involve some opening for debate and knowledge exchange to include, for example, membership organizations that have not been invited into STI discussions heretofore.

Explore regional and international collaboration: Consider the potential for regional or broader international collaboration in TA/TF activities. Shared problems can benefit from pooled resources and collective expertise, leading to more robust solutions. In large countries, subnational projects may be particularly effective, especially when aligned with a national framework. Collaboration at these levels can help address localized challenges while contributing to a cohesive national strategy.

Contextualise and localise TA/TF processes: TA/TF processes should be tailored to the specific needs and settings of the country. This means not only aligning them with national policies but also considering the unique contexts at the sub-national level. Localizing TA/TF processes ensures that they remain relevant and actionable across different regions, addressing their diverse challenges and opportunities.

Promote cross-sectoral TA/TF activities: Traditionally, TA/TF have been siloed within individual ministries, each focusing on its specific mandate. However, as trends in science, technology, and society increasingly overlap, collaboration across ministries is becoming essential. Countries like Canada and Portugal have addressed this by establishing cross-ministerial foresight bodies. These platforms facilitate interdisciplinary discussions

Institutional weaknesses can lead to failure if key departments do not actively collaborate or engage

International or regional collaboration can be beneficial, **especially for newcomers with little experience and budgets** and ensure that policy responses are integrated and coherent across different sectors, helping to break down traditional silos and address complex, cross-cutting issues more effectively.

Commissioning and Using Exercises

Select a project team based on capability and potential: The project team must be chosen for its capabilities or, where necessary, its ability to rapidly develop relevant expertise. Preferably, team members should already have demonstrated experience or have undergone training in the relevant areas. If no local capacity exists, and it cannot be developed within the required timeframe, external consultants—who may be based in specialist private firms, in non-profit organizations or networks, or in academic institutions—should be selected based on criteria beyond their reputation for quality work. One key criterion is their ability to provide a customised service, rather than reproducing work previously done for other clients. Another important criterion is their willingness to upskill local participants in the project work, enabling them to gain a solid understanding of the fundamentals and practical application of TA/TF methods.

Monitoring and evaluation are both important, **but are two distinct, although related processes**

Implement a robust monitoring system: The scoping of the project will have included plans to set up a monitoring system, which means the project team reporting on progress toward meeting milestones. Regular use of this system should help keep the project on track and provide early warning as to contingencies that are arising which imply change in plans.

Effective communication **is a critical element to reach key stakeholders** like policymakers and the public

Distinguish evaluation from monitoring: Evaluation is distinct from monitoring, and has more focus on the outcomes of a project (has it achieved the desired policy impacts?). Evaluation processes should be built into projects, as far as possible using assessors who are themselves independent of the project team (and thus with less conflict of interest in forming and reporting conclusions.) Good-quality project monitoring aids eventual evaluation considerably by providing key data that can be examined, e.g., recording the levels of attendance at workshops and dates of important meetings, identifying relevant participants and clients.

Engage the immediate client in shaping policy impact: The immediate client is bound to have a major role in shaping how far the recommendations and proposals from the project are understood and acted upon by relevant policy bodies. This will usually require keeping those policymakers informed about the project and its progress, which may be delegated to those members of relevant bodies who are already engaged in the project.

Establish a communication framework for ongoing programmes: When transitioning from a single project to a continuous TA/TF program, it is essential to establish a robust framework to regularly inform a broad range of policymakers about recent results and their implications for both STI policies and other related areas. This proactive communication strategy ensures that the insights gained are consistently shared and considered in broader policy contexts.

Cultivate good links with mass media: Media coverage may play important roles in disseminating messages from the exercises. Journalists and broadcasters may need assistance in grasping the significance and details of ongoing and completed work, and in checking the validity of their reportage. This goes beyond preparing press releases. Knowledgeable staff with good communication skills should be available for interactions, ranging from broadcast interviews and discussions to providing group or individual briefings on key topics. It may be helpful to have established relationships with relevant individuals in media organizations. If the practitioners who have implemented the exercise are liaising with media, they too may need support and guidance.

5.4 Recommendations for Practitioners

Methods

Ensure methodological diversity for high-quality TA/TF: Probably the most important determinant of quality in TA and TF is the mixture of methods they employ (assuming, of course, that the practitioners are capable of using these methods well, with due care to possible social and cultural sensitivities). This implies a combination of methods that are: (a) relying on data and its formal analysis by statistical or other approaches ("data-driven forecasting"), and methods accessing creativity and imagination (e.g., brainstorming, role-playing); (b) highly reliant upon accessing expert knowledge, including literature review, Delphi-type surveys, workshops, while others are more focused on broad participation of relevant stakeholders who have an interest in the technology and may be affected by it. The broader participation can provide insight into social dynamics and help raise awareness about the project and its processes. This, in turn, can build support for policies or, at the very least, make them more politically legitimate as they are informed by broader consultation with stakeholders in society.

Incorporate emerging techniques with caution: Stay abreast of machine learning and natural language processing methods, even if external expertise needs to be brought in. Some of the material produced by AI tools is valuable, but they should be used critically, as the tools are often marketed with a great deal of hyperbole, and with slick presentation of material that is more visually spectacular than truly informative.

Adapt methods to local contexts: Methods will have to be adapted to local circumstance. For instance, budget constraints may require less resource-intensive methods, the large size and transport problems of some countries may require more reliance on online methods. Knowledge about how far methods need to be adapted to local circumstances should be shared.

Build local expertise and capabilities: If practitioners are from overseas, they should build in training and skill development to support the development of local expertise and capabilities. This may go beyond training individuals, and include partnerships with local institutions like HEIs or local consultancies to provide knowledge transfer and embed TA/TF practice.

Incorporate sensitivity to social inequalities: Project teams should include members who are sensitive to and empowered to address issues related to gender, ethnicity, and other social factors. These considerations are crucial, as inequalities may be significant determinants of, or result from, technology trends and policy decisions. Ensuring that these perspectives are represented within the team helps to create more equitable and inclusive outcomes.

Engage internal and external project champions: In large TA/TF units, or in large consultancies or other bodies undertaking this work, it will not only be necessary to liaise frequently with product or process champions in government. Internal champions may be needed to support specific projects, especially where these involve controversial topics, the development of new methodologies, or participatory approaches in countries where these are unfamiliar.

Tailor presentation of results to diverse audiences: Again, a mixture of methods is recommended, tailored to different audiences. A lengthy report may have little impact on busy decision-makers, even with an excellent executive summary. Text can be supplemented with graphic illustrations. Scenarios are often well conveyed through narratives which present a compelling account of elements of a plausible future. Material needs to be prepared in formats suitable for a range of audiences.

Methodological diversity and local adaptation **are key to high-quality, inclusive TA and TF**

Frontier digital technologies like AI promise benefits **but must be integrated into TA/TF with due care**

Tailoring messages to the audience is essential for communication to be effective

Creating consent and mutual respect **create a credible process, build trust and promote engagement**

Promote futures literacy and set realistic expectations: Policymakers and stakeholders must understand that simply adopting TA/TF methods does not guarantee the success of STI policies. The value of foresight lies in enhancing the ability to navigate and shape potential futures, not in accurately predicting them. Judging foresight solely on its predictive accuracy is misguided and can lead to unrealistic expectations or negative perceptions. To address this, involve policymakers in the foresight process and integrate foresight into government operations, ensuring a shared understanding of its importance and realistic application.

Ethical and Related Issues

Addressing mismatches in expectations and norms: Especially when overseas practitioners are involved, there can be mismatch in expectations and norms, e.g., regarding the value placed on broad participation in the process, or on ensuring gender representation and diversity within working groups and other teams. These potential problems are not always encountered, but practitioners need to be prepared to confront them openly, and to both articulate their norms and recognise cultural sensitivities.

Navigating potential mismatches in goals and interests: There may be differences in goals between international funding bodies and national governments. Influential political or industrial actors may risk local ecosystems in the pursuit of growth, or fail to consider the needs of marginalised communities. For instance, many economists regard the informal sector as a nuisance to be done away with. External technologies may be desperately needed, but if delivered with insufficient knowledge transfer, they may lead to risky levels of dependency on particular suppliers, or of lock-in to particular solutions. It is not impossible that results of TA and TF will be misrepresented in local media coverage. Sensationalist journalism or pressure groups can take particular forecasts or scenarios out of context. Practitioners must possess strong science communication skills and be prepared to actively engage with stakeholders and the media to ensure accurate and responsible interpretation of results.

Ensuring consent and respect in participation: Issues of consent and confidentiality must be thoughtfully addressed. In Delphi studies, participants' anonymity is typically maintained, while workshops may be conducted under the "Chatham House Rule," allowing participants to use shared information but prohibiting disclosure of speakers' identities or affiliations. This approach can work well in private sector contexts, but government agencies, bound by transparency and records management regulations, may face limitations in applying such protocols. More broadly, all participants should be clearly informed of the purpose of the activity, including its intended policy relevance. This may require managing expectations and building trust. Respectful treatment of all participants must be a standard practice, and reciprocal respect among participants should be actively encouraged in all engagement formats.

Align TA and TF with top-level decision-makers and integrate across sectors: It is crucial that both TA & TF are closely aligned with top-level decision-makers and operate across ministries and sectors. To effectively promote technology in the country, it is necessary to engage with various areas such as industrial investments, education policy, and science and research. The focus should not be limited to any specific ministry. Instead, STI policy should be positioned at the highest level to ensure comprehensive and efficient promotion of technological advancements.

5.5 Recommendations for International Organizations

International organizations, NGOs and IGOs have been significant supporters of many TA and TF projects and programmes in the developing world. Many of the recommendations below build on activities in which these institutions already have considerable experience. The 2030 Agenda for Sustainable Development reinforces the importance of such support, particularly as TA/TF-relevant topics increasingly transcend national boundaries and take on global dimensions.

To maximise impact, TA/TF efforts should be approached from an international perspective. This helps avoid duplication, reduce fragmentation of resources, and promote more coherent global learning. While the recommendations below can be applied at the national level, they are also relevant to regional initiatives, which can offer efficient and effective ways to address shared challenges. For instance, establishing regional centres of excellence could prove valuable—provided mechanisms are in place to ensure strong links with national policymakers.

- **Funding:** funding can support both pilot and large-scale TA and TF projects or help underpin the establishment of new centres of excellence, or dedicated units within government or existing research institutes. Grants may be made available to fund individuals or institutions to collaborate on international projects and programmes of work. External funding is particularly important for encouraging countries to undertake work involving more novel techniques, or more participatory methods, or to pay attention to gender disparities and the circumstances of marginalised groups.
- **Capacity Building:** a critical issue is to build national capacities so that projects can be conducted autonomously, without extensive reliance on external expertise.[81] UNIDO, for example, has had extensive experience with providing short training courses and workshops to develop local expertise in relevant methodologies and techniques. Other approaches to mentorship are possible, such as organising placements of individuals from experienced organizations in developing country institutions, and vice versa.
- **Knowledge Sharing:** this can be accomplished by various methods, and some IGOs and INGOs have already made handbooks, toolkits, and guides to the field available. However, it is worth mentioning that these resources are often produced in English or other widely distributed languages, while local reports are usually written in one or several national languages most suitable for policymaking. This language difference may lead to additional work and financial burdens for some TA/TF institutions, as translating important texts becomes necessary to facilitate effective knowledge exchange. Some of these resources require more tailoring to the circumstances of exercises in resource-constrained environments. Conferences can support exchange of problems, experiences, and lessons as to good practice across countries. Online platforms could document TA/TF results, with detailed case studies. These could also support networks linking practitioners across the Global South, or regions therein, and provide developing countries with access to global databases (for example, of scientific literature), and to high-quality reports on technology trajectories. This can also support peer review and evaluation of projects.

International organizations should fund, build capacity and share knowledge **to strengthen TA and TF globally**

Funding support for capacity building and pilot projects **would benefit newcomers, especially small and low-income countries**

Sharing knowledge, methodologies, toolkits, good practices, national experiences and skills **globally is highly desirable**

81 Contribution from the Government of the United Republic of Tanzania.

Improving policymaker engagement requires raising awareness and, where appropriate, providing training

- **Policymakers engagement:** Many of the above points concern support for practitioners. However, the clients of TA and TF (policymakers) might also be supported. For example, workshops and conferences can be organised to provide guidance on the importance of integrating TA/TF results into policymaking, and on practical strategies for doing so. Policymakers may also need assistance in making the case for local initiatives within their national government contexts, and in building on the successes of pilot projects to secure sustained funding. Members of Parliament could be introduced to the experiences of relevant committees in other countries and/or be offered briefings or awareness-raising sessions on forward-looking approaches.

6. CONCLUSION

TA and TF are not cheap or easy tools, but they are nevertheless increasingly critical tools for all countries to harness the benefits of emerging technologies and mitigate the risks they create. These tools should be diffused as widely as possible across the globe. The only way to achieve this is through international collaboration and support for countries new to these disciplines that have little experience and capacity to use them but are willing to take domestic action to learn and use them. This report has provided recommendations for achieving this goal.

It is evident that neither TA nor TF is a cheap or easy process. While they may provide immediate benefits, such as informing technology choices or shaping national STI programmes, their true developmental impact may not become apparent for some time. Nevertheless, the world faces grand challenges and is undergoing complex, long-term shifts, marked in particular by sustainability transitions and digital transformation. Addressing these challenges requires robust strategic planning, which in turn demands an exploration of alternative futures and an appraisal of the role that STI can play in shaping desirable development paths.

This report concludes that both TA and TF can meaningfully contribute to these processes, with each approach suited to slightly different aspects of the task. While one may be more appropriate in a given country or context, it is prudent to develop and apply capabilities in both fields. Many countries, whether advanced industrial economies or those considered "developing", have established institutional mechanisms for conducting TA and TF and incorporating their insights into policymaking. There is significant potential for mutual learning, and countries that have not yet adopted

Collaboration and mutual learning are indispensable for countries **to harness benefits and mitigate risks of technological advances**

Domestic action supported by international collaboration offers our best hope **for continued and sustainable human progress**

these tools can draw on experiences from other countries around the world.

International organizations can amplify these national efforts by financing pilot projects, convening peer-learning and practitioner networks, and sharing methodological guidance and comparable case studies. The best prospects for progress will come from a combination of vigorous domestic action in TA and TF, and sustained international collaboration that builds synergies across subregional, regional, multilateral, and global levels.

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