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Issues Paper
on
Technology Foresight and Technology Assessment for Sustainable Development

Unedited Draft
Prepared by the UNCTAD Secretariat[1]

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EXECUTIVE SUMMARY

This issues paper 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.

Section 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 paper 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 identify the policy actions that will be needed to harness the benefits and mitigate the risks. The issues paper 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.

Section 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. These 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. Strategic intelligence helps prepare countries and communities for longer-term developments that can have significant positive or negative impacts in the short, medium or long term.

Section 3 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 strategic 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.

Section 4 presents recommendations for policymakers, TA/TF practitioners, the United Nations Commission on Science and Technology for Development (CSTD), and international organisations. While a “one size fits all” approach is completely unrealistic for countries with very different circumstances, problems, and opportunities, several general points are made. These recommendations focus primarily on two key aspects.

First is the need to have high-level support—“product champions”—for exercises and programmes. Without this, high policy impact will be hard to achieve, and projects may falter when encountering temporary problems.

Second is the need to develop and embed local capabilities. While foreign expertise may be invaluable in providing training and access to expensive databases and analytical tools, TA and TF processes should empower countries to cultivate their own futures culture and an ecosystem of informed and supportive people and institutions.

International organisations can play important roles in promoting and enabling such capabilities.

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
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)
COLCIENCIAS	Colombian National Department of Science, Technology and Innovation
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)
DSI	Department of Science and Innovation (South Africa)
DTU	Technical University of Denmark
ECAST	Expert and Citizen Assessment of Science and Technology (ECAST)
ECLAC	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
ESG	Environment, Social, Governance
EU	European Union
GMOs	Genetically Modified Organisms
FDI	Foreign Direct Investment
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
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)
IDRC	International Development Research Centre (Canada)
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
JRC	Joint Research Centre (EU)
MENA	Middle East and North Africa
MIEI	Ministry of Investment, Entrepreneurship, and Industry (Seychelles)
MIGHT	Malaysian Industry-Government Group for High Technology
MOTS	Ministry of Technology and Science (Zambia)
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
OECD	Organisation for Economic Cooperation and Development
OTA	Office of Technology Assessment
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
SAASTA	South African Agency for Science and Technology Advancement
SDGs	Sustainable Development Goals
SENAI	Brazilian National Service for Industrial Training
SIDA	Swedish International Development Cooperation Agency
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	UN Trade and Development
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
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

1. INTRODUCTION

This issues paper begins with brief definitions of the two main terms, Technology Assessment (TA) and Technology Foresight (TF), based on extensive literature review. These definitions indicate how these terms will be employed in the report. These terms are rather fluid and have been used for several decades—during which practices have evolved and the terms themselves have been applied to a range of activities, and been used in several ways.[2] We shall provide some examples of TA and TF to illustrate the practices and how they may be employed.

We shall here be 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 simply relying upon some especially insightful guru to pronounce on future developments. Both TA and TF also tend to be "systemic"—they examine technology-related phenomena taking place in 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, both "computer-communications" and "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. The two terms are outlined below, with some 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. But multiple adverse effects of scientific and technical innovations have become prominent public concerns in industrial countries since the early 1960s. Climate change, serious accidents in technical facilities, widespread experiences of 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

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

effects", such as disruptions to the labour market due to automation, began to receive greater attention (Balsmeier & Woerter, 2019). 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 that accompany 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 how policymaking and society should respond to these challenges.[3] The combination of these factors was an essential reason for the emergence 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 research field, with its own set of methods to combine scientific exploration of the issues with the practical application of the knowledge created, such as providing scientific policy advice (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 usually do not arise from technology and innovation alone. The underlying scientific and technical knowledge is applied through human actions, such as the use of technology and the consumption of its products. 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.

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-word issues. This impact may include providing usable knowledge for engineers in the design process of new technology, offering policy advice for political debate and decision-making, raising public

[3] Contribution from the Government of Poland.

awareness, or contributing to the wide range of actions involved in sustainability transitions, for example.

History and current status

TA can be traced back to a specific political environment more than fifty years ago, within the United States Congress. The Office of Technology Assessment was established in 1972 to support Congressional deliberations, with the aim of aiding decision-making in policy fields affected by scientific and technological advancements, analyzing unintended side-effects of technological progress, and weighing the associated risks and opportunities.

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, increasingly expanding worldwide and becoming institutionalized as for example 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.[4] 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.

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.[5] 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.[6] Ideas for topics to consider are presented by committees and parliamentary groups of the German Bundestag, TAB responds as to 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

[4] 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.

[5] Contribution from the Government of Germany.

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

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 also working on diversifying 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.

Following TA developments in the 1980s and 1990s, activities currently practiced 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 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 can help ensure that diverse perspectives are included, and that ethical and societal considerations are more thoroughly addressed.

(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 and/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 society and economy (Plekhanov et al., 2023), the diagnosis of the Anthropocene[7] (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).

The urgent need for sustainable development, combined with the escalating threat of climate change, has further driven the necessity of transformation in our sources and uses of energy, pushing TA to address these global imperatives. Furthermore, the demand for orientation in the post-colonial era has prompted a critical examination of practices that might facilitate a resurgence of neo-colonialism (Arnold, 2005). Therefore, there have been efforts to "decolonize" many fields of enquiry and debate.

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 all practitioners will sign up to. 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 shared across the TA branches mentioned above: 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-

[7] 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 (Crutzen, 2002; Crutzen & Stoermer, 2000).

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. 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 (e.g., 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.[8] 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.

Hermeneutic TA: The uncertainty of prospective knowledge and sometimes its complete absence motivates 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 uncovering 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*".

[8] 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/

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 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 risk, 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.[9] BTA involves assessing how a technology aligns with the organization's strategic goals, such as its potential to enhance efficiency, competitiveness, and innovation. Regulatory or consumer pressure may lead to sustainability issues being built into such BTAs, and investors are increasingly examining the Environment, Social, Governance (ESG) ratings of businesses.

Definitions and examples

In this issues paper, 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,

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

2024). However, over the past 20 years, with the emergence of new technologies like nanotechnology and synthetic biology, TA has evolved. The Vision[10] Assessment approach within TA, for example, specifically addresses possible long-term issues (Grin & Grunwald, 2000).

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 particular projects, though organisations like the International Labour Organisation (ILO) and UN Women are working to broaden this scope to include gender and job equality issues.

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 introduce. 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.[11] This is where foresight methods become crucial. Therefore, a well-rounded TA approach must incorporate foresight methods, as it is essential to consider future outcomes and consequences.

In the 1970s and 80s, 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,[12] which recommended 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

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[10] 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 (Grin & Grunwald, 2000; Schneider et al., 2023).

[11] Contribution from the Organisation for Economic Cooperation and Development (OECD).

[12] 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

of the original OTA. 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 many 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.

This blending of TA and TF demonstrates that it is more productive to view these approaches as complementary rather than entirely separate. Both approaches play crucial roles in technology governance, and their integration can significantly enhance the effectiveness of both TA and TF exercises. In particular, recent technological advancements—such as Artificial Intelligence (AI), gene editing technology[13] and quantum technology[14]—underscore the need for a robust connection between TA and TF. There is an ever-growing need to conduct TA to assess immediate issues in the short term, while TF provides a framework for forecasting longer-term possibilities and preparing for future 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 10 years or more. 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.

TF usually engages multiple stakeholders alongside experts knowledgeable about a range of technologies and their applications.[15] 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

[13] 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/

[14] 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/

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

political legitimacy from involving a range of interest groups and going beyond the "usual suspects" who traditionally provided advice on STI policies.

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 or strategic research in addition to applied R&D. On the other hand, the effective uptake and use of technological opportunities, while avoiding unnecessary risks, requires adequate contexts to facilitate innovation. This may involve addressing real concerns that can underlie opposition to some technology developments.[16]

While much ForSTI follows "classic" TA practice and begins by examining technological opportunities, increasingly exercises are oriented around major social or environmental problems. In the latter case, where issues of sustainable development are increasingly prominent, the aim is to identify measures that may contribute to addressing these challenges, while considering evolving socio-political circumstances. The emphasis will often be on planning for R&D, technology innovation and adoption, and human resources for STI. While TF (and ForSTI) may be undertaken for various clients, many of the key exercises undertaken here have been at the behest of government ministries or departments concerned with STI, particularly those responsible for the funding of R&D and developing relevant skills. Ministries and departments with environmental and related responsibilities often undertake these activities too.

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, recent work being reported to impact such areas as robotics, AI, and renewable energy technologies. 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

[16] 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.

STI policies. For example, in Portugal, foresight methods were introduced with the Science Law in 1986.[17]

The experience of Japan and later the USA led the EU[18] to use TF exercises to shape its multi-year research and innovation "Horizon Europe" funding programmes (**Box 2**). These 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).

Technology forecasting (TF) is conducted by various entities, including large companies that may have dedicated in-house teams focused on analyzing technological developments.[19] 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 organisations.

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

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[17] Contribution from the Government of Portugal.

[18] 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 promote collaborative approaches within the EU member states.

[19] 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

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.[20]

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 forecasting 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 and text mining from databases like PATSTAT and SCOPUS. 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, 2020), 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.

The United States is a country with a rich *TF ecosystem*, even though the US government has not run the sort of large-scale TF programme 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.[21] 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,

[20] Contribution from the Government of Austria.
[21] 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.

and awareness of those involved in foresight, often operating outside of formal government structures.

The decentralized model is by no means the only approach adopted. Russia, for example, 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.

Institutional forms of 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.[22] 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.[23]

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.[24] This portfolio terminology is frequently encountered in the titles of numerous publications and conferences, though it appears to remain most popular in Europe.[25] Here we will use TA/TF to cover the ensemble of approaches. **Table 1** sets out to contrast

[22] Contribution from the Government of Portugal.
[23] Contribution from the Government of Portugal.
[24] 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.
[25] FTA is sometimes replaced by Technology Futures Analysis (TFA) which arguably places more emphasis on the technology than the futures-orientation.

"classic" forms of TA and TF, but it must be conceded that there is much overlap between the two practices. This is hardly surprising, since both are concerned with new and emerging technologies in their socio-economic contexts.

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, etc. 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 is arguable that over time these activities have become more similar in many of the features mentioned above. There are also overlaps between one or both of the two broad activities with a number of other activities, such as risk management, preparedness planning, resilience; and also climate change and ecosystem modelling and analysis, Environmental Impact Assessment, and so on. Each of these activities has its own communities and publications.

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, where 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).

Table 2. Evolution of TA and TF
(focusing on issues driving development and use of these approaches)

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. 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. and Gilfillan S. C. also contributed to early technology forecasting, using quantitative measures. Wells H.G. 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' (1970) spurred interest in anticipatory governance. The U.S. Office of Technology Assessment (1974) 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' (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

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.

In the longer-term, social, economic, and environmental conditions may have changed considerably, and the forms taken by technology design and uptake, are much 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 technology 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.

1.4 TA and TF 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.[26] 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,

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

systems dynamics). Some methods focus on gathering and combining 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 approaches.

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.

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 towards asking, "what if?" (so-called exploratory techniques), while others towards "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.

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 and actionable 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.

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. For example, perspectives like Afrofuturism aim to provide more authentic and decolonial viewpoints (Womack, 2013). There has also been a growing interest in equity-based, anti-colonial perspectives in both TF and TA, emphasizing the importance of diverse narratives in understanding and shaping the future of technology (Mohamed et al., 2020). 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 consider the diversity of experts involved in 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.

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

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 help shape preparedness to adopt and adapt these technologies, and where possible, to 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 in helping a range of different government departments and agencies coordinate their efforts to bring about long-term change in addressing problems which require policies across this range. A case from the UK involved flooding, the subject of a problem-driven TF exercise, where government departments responsible for housing and construction, road-building, 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, an exercise addressing obesity engaged those responsible for sports, food, education and health—and to which the food industry reacted in a less accommodating manner.[27]

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[27] 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.

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 better knowing 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.

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 organisations. Public sector organizations may be critical users for establishing standards for technology adoption.

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 and Botswana).

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 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 attacks (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 even catastrophic human error (as in the CrowdStrike cybersecurity crisis in July 2024). 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 better suited to a country's specific needs and the current state of its National Innovation System (NIS).[28] By aligning technological innovations with national socio-economic and innovation systems, TA/TF can play a crucial role in designing more effective and future-proof industrial policies. This involves integrating cutting-edge technologies into the core of new industrial strategies, enhancing national competitiveness, and better preparing countries for future risks and crises.

[28] 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).

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.

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

Both TA and TF, along with broader STI policymaking, have evolved from a predominantly technology-centric focus to a more problem-oriented approach. This shift towards greater directionality[29] of STI policies is characterized by an increasing emphasis on proactively designing solutions for global grand challenges[30] (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 on analyzing a portfolio of technological solutions and their interactions within broader value chains and systems.

Another significant shift in TA/TF practices is the increasing integration of **values** through extended stakeholder and public engagement. This shift moves beyond technical analysis to incorporate diverse perspectives, ethical considerations, and social values. These engagements are carried out through deliberative exercises such as the

[29] 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.
[30] 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.

Conference on the Future of Europe,[31] where public discourse and inputs shape future policymaking.

There has been an increased focus on **governance** within the fields of TA/TF. Governance is not limited to setting high-level goals for scientific research or managing the consequences of technological advancements after they are deployed. Rather, it includes active engagement at all stages of the innovation process, particularly in the "midstream" phase that lies between "upstream" agenda setting and "downstream" adoption and regulation.

This phase, as proposed by Fisher et al. (2006), focuses on research, experimentation, design, and development—areas that are often overlooked when it comes to guiding technological development in a socially responsible manner. **Midstream governance** offers a way to steer scientific and technological trajectories toward more sustainable outcomes by integrating ethical reflection and stakeholder input during R&D.

Governance in this context differs from "government" in that it operates across multiple levels and involves a variety of actors, including "insiders" such as policy makers, scientists and engineers, business leaders and entrepreneurs as well as "outsiders" such as ordinary citizens and civil society organizations. This multi-level and multi-actor approach highlights the importance of **capacity-building** among diverse stakeholders to ensure that scientific and technological innovations align with societal values and address global challenges effectively.

Other terms like **mission-oriented innovation policies** are widely deployed to emphasize the strategic direction of R&D efforts toward specific goals (Mazzucato, 2018). This approach is about setting clear objectives that can mobilize resources across various sectors. 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 for 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 shift in TA/TF practices and broader STI policies toward addressing global 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

[31] For more information, visit https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/new-push-european-democracy/conference-future-europe_en

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, governance, and equity. By innovating within the boundaries of existing systems, we may continue to replicate the same unsustainable dynamics, leaving deeper systemic challenges unaddressed. There has been a recent push towards the development of transformative innovation policies that target underling sociotechnical systems to create deeper transformative changes to meet societal challenges and promote sustainable development (Diercks et al., 2019; Schot & Steinmueller, 2018).

It is also important to recognize the inevitability of value conflicts (also of "ambivalence") in STI policies. 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 social justice.

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). 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 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, highlights governance gaps that must be addressed to facilitate systemic transformation. Similarly, TF can aid in exploring new governance models that can better support innovation ecosystems geared toward global grand challenges, such as mission-oriented innovation policies that bring together public and private sectors toward common goals.

Both TA and TF help to ensure that innovation policies are aligned with broader societal missions and stay on course. TA assesses whether specific technological innovations contribute to or detract from these missions, while TF helps 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. While Japan has been able to run large-scale Delphi studies every few years, there seems to be less appetite for this in Western countries. While some forms of horizon-scanning and technology watch have been ongoing, they have tended to undertake more focused "deep dives" into specific technologies and problems, including problems with the NIS itself.

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 research and development 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, choice and implementation of strategies are political affairs.

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 will tend to be employed when immediate decisions are required about, for example, location of power stations, types of power production and distribution to be employed, the infrastructures required, and so on. While immediate, these decisions can have very long-term consequences, since the facilities involved can have lifetimes of decades.[32] A

[32] Large and complex projects often turn out to encounter unanticipated issues once work has begun on them. Many such issues require revisions of estimates of benefits and, especially, costs of particular

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 policy decisions inherently political ones.

TA can provide realistic guidance as to how well-founded claims as to 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 rather sectoral focus, and it may be commissioned by a range of government departments and industry bodies—not just the ministry responsible for STI policy.

While TA focuses mostly on the immediate implications of current 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. Many people will be familiar with the so-called "Moore's Law" describing the decades-long steady increases in the number of transistors that can be fitted onto an integrated circuit.

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, less demanding of inputs of energy and scarce resources. This is not inevitable—some technology applications change very slowly, while trajectories may have negative features. For example, the current generations of AI that are being built into much computer use, requires substantial increases in energy consumption (UNCTAD, 2024c), though this is expected to be less necessary in the future (Verdecchia et al., 2023; Wu et al., 2022).

These technological trajectories are typically experienced globally and are largely determined by the production and application of new knowledge, often based on general-purpose technologies such as those involved in information technology or

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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 a stable one. Facilities might be designed, for example, so that they could be adapted to better fit the changed circumstances.

biotechnologies. The development of such knowledge reflects the incentives of major stakeholders, many of whom are large businesses with global reach and are primarily concerned with their profit margins.

In some advanced technology areas, particularly AI development, these businesses are leaders in strategic research, where R&D involves development of fundamental knowledge. Universities and public research institutes have more traditionally been the main sources of such fundamental knowledge, though spin-offs and joint ventures may move such knowledge rapidly into application, as was notably the case in the development of vaccines for COVID-19 (WHO, 2020).

Some well-resourced national governments deploy various tools to develop and apply knowledge in addressing environmental concerns and SDGs (**Box 3**). They can use regulatory and other measures to influence markets, e.g., tax relief, subsidies, and public procurement, they can support R&D, demonstration programmes, education and training. 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 3. 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—industry, academia, government, and civil society—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 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 strategies for becoming fossil free are resilient and adaptable.

Sustainability is a more prominent feature of current technological trajectories, especially in relation to energy production, but may not be an underpinning principle, as seems apparent in several areas of IT.[33] The development and use of AI is a case where government action seems to be mainly regulatory (at least, in the case of countries with technological leadership here; other countries are mainly playing catch-up). TA efforts of

[33] Businesses and public sector organisations are often accused of "greenwashing", when they make claims as to commitment to sustainability which are superficial, or when "greener" practices are mainly intended to reduce energy or scarce resource costs, or to satisfy current market or community demands. How far such practices can be embedded is an open question.

various sorts have come into play in order to support examination of impacts of ongoing trajectories in technological performance and application of emerging functionalities.

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).[34]

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, 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 as to 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

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

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.[35]

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 organisational changes, such as "sharing economy" 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 the socio-technical changes affect the differential domestic work and formal employment circumstances of men and women.[36] 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.

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.

Vulnerability and Resilience of Critical Infrastructures

Infrastructures are regarded as lifelines of societies and economies. Secure energy networks, water supply, transport pathways, food supply, education, health, information and communication, form the backbones of social, political and economic life at all levels. However, in recent years, severe vulnerabilities and weaknesses have been

[35] Contribution from the United Nations Environment Programme (UNEP).
[36] 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/

exposed—most notably during the COVID-19 pandemic,[37] as well as through terror attacks, wars, extreme weather events driven by climate change, and cyber-attacks.

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*[38] and asked the question: If such a blackout happened, *what* would happen *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. Hospital 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 piece of TA 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

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[37] See the work of Policy Horizons Canada. Foresight on COVID-19: Possible shifts and implications, available at https://horizons.service.canada.ca/en/2021/03/05/foresight-on-covid-19-possible-shifts-and-implications/

[38] 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.

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.

Sustainable Development – the Role of TA and TF

Sustainable development is a topic that cuts across many areas of government, and merely considering it as a topic 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 sustainable development are parcelled out across different ministries or government departments. 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 is a step towards understanding how STI policies contribute to and support sustainable development efforts, but the policy mix extends well beyond research and development funding. While some research funding is aligned with sustainable development—directed, for instance, toward providing clean water, enhancing agricultural sustainability, or creating affordable medical technologies—the broader policy landscape includes many other elements that influence progress toward the SDGs.

Sustainable development action raises issues of financing and market development, technology transfer and 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. Diffusion and use of innovations is often particularly relevant when it comes to SMEs, who may lack knowledge and resources to take them up.

More generally, STEM education on 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 individuals to work from home or helping partially sighted or blind people navigate 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. 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 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 a 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 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.

TA relates more to parliamentarians and others concerned with making and reviewing more immediate decisions about choice of technologies and of 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.

A more integrated approach should aid navigation of the inevitably complex transition to sustainable development, in which 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.
2. Both can help improve the public and policymaker understanding of STI choices and options, and of wider social, environmental and ethical issues.
3. Both introduce evidence into policy discussions that may traditionally be made on the basis of personal hunches and assumptions.
4. Both may support the efficient allocation of limited resources,though for different aspects of STI development. Additionally,both may provide input for for planning skills development, infrastructure activities, and overall strategic planning.

5. Finally, both can benefit from international cooperation, including regional and South-South cooperation. Such cooperation may also enhance capabilities to negotiate technology transfers, and to move beyond passive consumers of foreign technology, to learn about and master key aspects of the underpinning STI.

On the other hand, the two are often at opposite ends of a spectrum, ranging from immediate and short-term technology choices to longer-term and strategic efforts, to revitalise the NIS around future STI opportunities. They do 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, too.

TA typically focuses on environmental, social, and economic impacts of technology, 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 that technological change has in general 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 paper takes the view that there is rapid technological change in many technology areas, notably among digital technologies and some other frontier technologies.

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 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 action in STI development is taking place in other regions of the world. It can be useful to locate and examine the results of reviews and similar work carried out elsewhere, to timely determine whether the emerging topics require further examination. International organisations 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 organised. 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).

In some cases, both TA and TF are required. Many 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[39] may be diverting us

[39] It should also be noted that the imminence of Artificial General Intelligence is much contested, with some commentators putting it less than a decade away, while others suggest that it is at least several decades from realisation. See, for example,

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, use of AI in weapon 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). 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 breathless 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.

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https://wiki.aiimpacts.org/doku.php?id=ai_timelines:predictions_of_human-level_ai_timelines:ai_timeline_surveys:2022_expert_survey_on_progress_in_ai
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2.5 Digital Transformation of TA/TF

The rapid advancements in digital technologies are transforming TA/TF methodologies.[40] 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 (OECD, 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 render material available in different styles. They can even allow for some visualisation of ideas and narratives and 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, where work is being undertaken. Such methods were employed in Brazilian, Japanese, Russian and South African exercises. 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

[40] Contribution from the International Telecommunication Union (ITU).

foresight. Notable examples include the Joint Research Centre (JRC)'s Text Mining & Analysis Competence Centre (TMA-CC),[41] the U.S. Government Accountability Office (GAO)'s Science, Technology Assessment, and Analytics (STAA) team[42], Higher School of Economics (HSE)'s Intelligent Foresight Analytics system (iFORA)[43], and Nesta.[44]

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

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 policy-making, 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 organisational 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 organisational 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 a relatively close time horizon in a South African TF exercise[45] (**ANNEX**), 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 more

[41] For more information on the European Commission's work in text mining, visit https://knowledge4policy.ec.europa.eu/text-mining/about_en
[42] Learn about the GAO's Science, Technology Assessment, and Analytics (STAA) at https://www.gao.gov/about/careers/our-teams/STAA
[43] For details on the IFora project by the Institute for Statistical Studies and Economics of Knowledge, visit https://issek.hse.ru/en/ifora/
[44] 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/
[45] Contribution from the Government of South Africa.

incremental development. 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 the 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 following 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, costs of the technology will have reduced, it will have become more reliable and user-friendly, dominant design features will have stabilised (and sometimes a few platforms take over the landscape), the skills and capabilities required for production and use will be 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 certainly means 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. Policy-makers 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” against, or at least have requisite flexibility built into them; 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 are 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 smaller-scale and rapid exercises are liable to be vital in the context of rapid change, and their success will help build the case for ongoing work.

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 been typically the case in industrial 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 world regions where little has been accomplished in these fields to date.

There have been some related initiatives from such bodies as UN Trade and Development, UNESCO, and UNIDO, along with regional bodies, some foundations and professional networks. Currently, there is a proliferation of global 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.

3. OVERCOMING CONSTRAINTS IN TECHNOLOGY ASSESSMENT AND FORESIGHT

3.1 Challenges in Implementing TA/TF

In most countries, one of the most fundamental challenges in implementing effective TA/TF activities is the scarcity of financial and human resources.[46] 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.[47] 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 equipped to handle TA/TF activities, 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 research-policy interface in many countries 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.[48]

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 these 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. When key players do not fully comprehend or value the TA/TF process, it becomes challenging to

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[46] Contribution from the United Nations Technology Bank for Least Developed Countries (UNTBLDC).
[47] Contribution from the Government of Oman.
[48] Contribution from the Government of Germany.

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 the policy-making process. 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 points or communicating regularly with them on results during a TA or TF exercise may help. Countries new to TA and TF might seek means to establish linkages from the beginning when adopting use of these tools. In one recent example, the UNCTAD methodology for its pilot project on TA in African countries suggested establishing a Steering Committee to help provide a link to high-level officials and policymakers (see **ANNEX 6.1** on country experiences).

Access to research outputs and bibliographic databases presents a critical challenge in many developing countries.[49] 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, these countries are at a disadvantage in making informed decisions about future technological and economic developments.

The sectoral approach to TA/TF activities, where the focus is narrowly on specific industries or technologies, can also limit the broader applicability of TA/TF results.[50] 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 Indonesia. Without active participation from industry stakeholders, TA/TF exercises risk missing out on critical insights related to market needs and trends. This lack of engagement can lead to TA/TF activities that are disconnected from the practical realities

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[49] Contribution from the United Nations Industrial Development Organization (UNIDO).
[50] Contribution from the Government of Cuba.

of the market, reducing their effectiveness and relevance to policy-making and strategic planning.

In many developing countries, there is often a lack of interest or motivation among potential respondents to participate in TA/TF exercises, such as Delphi surveys.[51] 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.

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[52]. 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.

Managing clients' and customers' expectations is another challenge, particularly in countries like the Philippines.[53] 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 scenarios with the formal planning process is crucial but challenging. 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 complicates the process of integrating new solutions into established systems. This misalignment between technological innovation and regulatory frameworks can 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

[51] Contribution from the Government of the Islamic Republic of Iran.
[52] Contribution from the Government of Indonesia.
[53] Contribution from the Government of the Philippines.

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.

3.2 Learning from Countries' Experiences

In countries with more 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. 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.

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.

Such a system requires sustained support from policymakers, and several of the cases described have been long-standing, indicating they have continued to garner 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 understandings of 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. Experience in some Western countries demonstrates that TA and TF can be constrained by political actors. For instance, the USA's Office of Technology Assessment (OTA) was closed in 1995, though its functions were later institutionalized under the United States General Accounting Office (GAO), where TA is actively conducted to provide assessments for the United States Congress.

Similarly, the UK's Foresight Programme was significantly diminished due to cuts in civil service budgets in the latter part of the 2010s.

This suggests that 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 reports on global technology developments, that are much better-grounded than typical journalistic coverage of the imminent revolution or disaster that modern STI will bring about.

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 is not unknown. 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 much less 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, though it will not be enough to delegate responsibility to a random member of staff.

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 industries.

In terms of securing policy impact, the STI agenda may be reaching a critical point, with the need for policies to address particular 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 well-evidenced. 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 the ongoing support, of course. The technical quality of work can be assessed by expert peers, which may require reaching out to global TA or TF communities. But more documentation of policy impacts, and lack of impacts in some policy areas and communities, could be revealing. It is not unknown for policy formulation and implementation to diverge in crucial respects from the recommendations that they are supposedly based upon.

4. RECOMMENDATIONS

4.1 Organisational Issues

4.1.1 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 remains somewhat 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 challenging.

There are three main decisions involved: (1) scope of the work; (2) 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 and similar institutions are able to prepare rapid briefings about developments that are new to government, 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 unites are well-informed about where and how to access such expertise. It may be possible to draw on work that has been conducted in other countries, where TA teams may well have addressed similar demands.

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 take into account technological trajectories as well as demographics and the like. Many of the initial wave of TF programmes in the 1990s and shortly after were commissioned without original intentions for ongoing work. In several cases, it was assumed that results would simply feed into an STI plan that would guide development for at least a decade.

Ongoing activity

On the other hand, an alternative approach involves establishing or maintaining a permanent unit within the government, or an external centre of excellence, that goes beyond merely responding to government requests. Such a unit would play a proactive role in setting the agenda for its work. This is likely to involve some combination of ongoing assessment of the technology landscape, together with "deep dives" into specific technological challenges and/or problem areas where STI is liable to play a large role in addressing the issues.

Some specific areas 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 necessarily have to be able to undertake or commission such appraisals, and to be able to act on their outcomes.

Location of the work

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

Externally

When the government has little experience of TA/TF work, then it can make sense to employ external expertise, which may even be sources from other countries. If external contractors are engaged to lead specific projects, there still needs to be at the minimum internal capabilities to manage their work and relations to policymaking. More may be gained by associating particular staff members, recruits, or researchers/advisors based in national institutions, to work with and learn from the consultants, thus developing local capabilities in the effort.

Internally

The internal team will need to have had training and/or experience with the application of these methods, be equipped with adequate facilities to conduct the exercise themselves, and establish a programme of work if the activity is proving helpful to policymaking.

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 unit based in government 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". This capacity 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, these will need to have a point of liaison with the unit most frequently responsible for this work. 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, ready recourse to an institution and/or network that can provide adequate evidence is almost always important.

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, notably in the Asian and Brazilian governmental "think tanks" discussed in **Annex 6.1**. 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 higher education institutions (HEIs), research institutions, and consultancies, as well as in various parts of government and 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.

4.1.2 International Level

International organisations 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. There have been several efforts by bodies such as the EU and OECD to establish networks for exchange of experience between practitioners (and sometimes users) in different countries.[54] Several of the countries discussed in **Annex 6.1** having had considerable support from UN and other bodies in their activities,[55] and they have learnt from good practice elsewhere.

Such collaboration on TA/TF is valuable, but seems to be rather opportunistic. It may well make sense to establish global platforms that could work to raise the standard of TA/TF in general and to support those countries that are embarking on related activities for the first time or from a fairly limited base. For example, there is very little documentation of the evaluation of projects and their results. Among support mechanisms could be:

- 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.
- Support for 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.

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[54] 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

[55] 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

- Compilation of accounts of good practice, including ways of achieving diverse and inclusive participation, of rendering technical output suitable for less technical audiences, etc. Encourage 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).
- Work 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.

4.2 Practical Issues

The discussion below provides a range of recommendations addressed first to policymakers, and second to TA and TF practitioners. Later, we consider international organisations, who can be important players in the development of TA and TF. 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, the willingness of their coordinators to engage with your country.

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.

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 organisation 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 organisations. 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 impacts 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.

4.3 Recommendations for Policymakers

Organisational Issues

Establish or enhance TA/TF centres: If centres dedicated to Technology Assessment (TA) or Technology Foresight (TF) do not already exist, initiate the formation of a team to scope potential projects that will inform upcoming STI-related decisions. Scoping is a task to take very seriously. 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), and 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 organisations 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 it 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 the 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 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 in terms of capability, or their ability to rapidly develop relevant capabilities. Preferably they already have demonstrated experience and/or undergone training on relevant topics. If no local capacity exists, and it cannot be developed in the time available, the choice of external consultants—who may be based in specialist private firms, in non-profit organisations or networks, or in academic institutions—should be made on several criteria, other than simply their reputation for quality work. One key criterion will be their ability to provide a "customised" service, rather than reproducing work they have already undertaken for other clients. A second criterion will be their willingness to upskill local participants in the project work, so that they have learnt much about the fundamentals and practice of the TA/TF methods.

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.

Distinguish evaluation from monitoring: Evaluation is distinct from monitoring, and has more focus on the outcomes of the projects: have they 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 – for instance, the levels of attendance at workshops can be examined, relevant participants and clients identified.

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 organisations. If the practitioners who have implemented the exercise are liaising with media, they too may need support and guidance.

4.4 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. The latter provides insight into social dynamics and helps raise awareness about the project and its processes. This can build support for policies or, at the very least, make them more politically legitimate. and those much more based on wide participation.

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.

Cultivate good links with mass media: As noted when making recommendations for those commissioning the study, media coverage may play an important role in disseminating messages from the exercises. Journalists and broadcasters may be encouraged to take this role on but may need assistance in grasping the significance and details of ongoing and completed work, and in checking the validity of their reportage. Knowledgeable practitioners with good communication skills should be prepared to take on this role, which may mean one-to-one interactions but could extend to being interviewed to taking part in discussions and debates. Exactly how to proceed with the media may need to be discussed with project sponsors, who may have had bad experiences (negative publicity) in the past.

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 the general public and community-level stakeholder groups, for strategists in economic sectors—primary industries, agriculture, manufacturing, services (including public services), for policymakers (not only STI policymakers)—and for those who have been engaged in the project, to employ within their own organisations.

Promote futures literacy and set realistic expectations: Policymakers and stakeholders must understand that simply adopting foresight 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 of expectations and of norms, e.g., considering wide participation in the exercise, or in seeking 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: Other potential mismatches may have to be taken into account. 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. Good science communication skills, and preparedness to make the effort to use them, are required.

Ensuring consent and respect in participation: Issues of consent may arise: participants' anonymity is typically provided in Delphi studies, and workshops may be governed by "Chatham House rules". These are, in essence, that participants are free to use the information received, but may not reveal the identity nor the affiliation of those providing the specific information; sometimes there will be restrictions on making data about participants in general, but often people want their engagement in TA or TF activities to be known. More generally, participants need to be informed of the purpose of the activity they are engaged in, which may involve management of unrealistic expectations, as well as showing that a policy impact is intended. Participants in workshops and the like should be treated and treat others with respect.

Align TA & 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, technology and science policy should be positioned at the highest level to ensure comprehensive and efficient promotion of technological advancements.

4.5 Recommendations for International Organisations

International organisations, NGOs and IGOs have been significant supporters of many TA and TF projects and programmes in the developing world, and many of the recommendations below are that they extend activities in which they already have experience. The 2030 Agenda for Sustainable Development makes such supportive activities even more important, especially as TA/TF-related issues and topics are becoming more global in scope. To maximize impact, TA/TF insights should be approached from an international perspective, ensuring that efforts are not duplicated, and resources are not fragmented.

The recommendations below can be oriented to regional as well as national projects: often joint initiatives can be valuable ways of addressing common problems. It may be that regional centres of excellence are viable, though this would require methods to ensure that these maintain sufficient contact with national policymakers.

- **Funding**: this 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, in the field in the developing country. Grants may be made available to fund individuals or institutions to collaborate and join into international projects and programmes of work. It may be that 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.[56] 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 organisations in developing country institutions, and vice versa.

[56] Contribution from the Government of the United Republic of Tanzania.

- **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. These efforts are much more oriented to sharing than just dissemination of work, and could have important contributions to make to the development of appropriate ethical frameworks for this work in developing countries of different types.
- **Policymakers:** Many of the above points concern support for practitioners. However, the clients of TA and TF might also be supported. For example, workshops and conferences might be organised to provide advice and understanding of the need to integrate, and the ways of integrating the results of projects into policymaking. They can be given support for making the case for local exercises in their national government contexts, and how to build on the positive experiences of pilot projects and maintain funding streams for this work. Members of Parliaments could be introduced to the experiences of relevant committees in other countries, and/or be provided with brief awareness-raising sessions on forward-looking approaches. The experiences of recent years—financial instability, climate change impacts, geopolitical turmoil, technology breakthroughs—have created an appetite in many regions for more understanding of the ways in which more anticipatory governance can be achieved.

Recommendations for the CSTD

Mobilize resources and promote best practices: A crucial role for CSTD is the identification and mobilization of resources, particularly for countries with lower levels of technological development Apart from the support of the United Nations, and that of other IGOs, there may be scope for mobilising funds from national development assistance organisations, and even from well-intentioned philanthropists. CSTD can act as a facilitator by identifying and promoting best practices in the implementation of TA/TF, enabling these countries to leverage successful models and strategies.[57]

Develop international standards and tools: It would be highly beneficial to establish common methodological standards for TA/TF at the international level, enabling the comparison of national results and fostering consistency in global technological assessments. Expanding the international dialogue concerning TA/TF tools and methods would also be advantageous for all partners, allowing for the identification of common challenges and coordinated responses.The development of shared tools for TA/TF would also be advantageous, allowing for the identification of common challenges and coordinated responses.[58] Leveraging existing frameworks such as the UNCTAD TA methodology could serve as a foundation for these efforts.

Promote regional Cooperation in TA/TF for Global Challenges: Regional cooperation is vital in addressing global challenges and advancing the SDGs. The CSTD should actively promote regional collaboration in conducting TA/TF studies, focusing on global challenges and the SDGs. This could include organizing workshops and producing joint reports that reflect regional actions and strategies aimed at overcoming global challenges and achieving sustainable development. [59]

[57] Contribution from the Government of Cuba and the Government of Ecuador.
[58] Contribution from the Government of Switzerland.
[59] Contribution from the Government of Türkiye.

5. CONCLUSIONS

It is evident that neither TA nor TF are cheap or easy processes. While they may provide immediate benefits, such as helping to make 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 a complex, long-term transition, with a key element being the shift from fossil fuel-dependent economic systems to more sustainable ones based on clean energy and circular economy principles. Addressing such complex, long-term issues require robust strategic planning, which in turn demands an assessment of alternative futures and an appraisal of the role that STI can play in shaping desirable development paths.

This issues paper 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 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 these approaches can draw on experiences from around the world. There is also considerable scope for intergovernmental organizations (IGOs) and international non-governmental organizations (INGOs) to play a supportive role in this endeavour.

6. ANNEX

6.1 Technology Assessment and Foresight in Developing Countries

This section reviews experience in TA and TF across the developing world. Developing countries 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.

It is also important to note that documentation of TA and TF efforts in developing countries is quite limited, particularly regarding the actual impact these efforts have had on policy and planning.[60] As a result, the review that follows is necessarily partial and incomplete. However, the experiences discussed provide enough insight to derive some meaningful lessons.

Over a decade ago, a review of "New Models of Technology Assessment for Development" (Ely et al., 2011), argued that technology has not been reaching its full potential in improving people's lives around the word and supporting sustainable development pathways. TA—their use of this term includes TF—involves collecting, producing, interpreting and evaluating evidence and perspectives around contending technological options. This is used to assist in identifying priorities and in improving the cost-effectiveness, environmental sustainability and long-term impact of technology policies and investment, particularly in fields like health, energy, and agriculture. TA can help ensure that technologies serve their desired functions, and that negative impacts are foreseen and, hopefully, avoided or at least mitigated. However, in practice, actual use of TA often fails to deliver on this potential, and the authors see this as particularly an issue in developing countries (Ely et al., 2011).

TA needs to grapple with social, technical and ecological complexities and uncertainties, and the power relations that often drive technological choice. Ely et al. (2011) concluded that more participatory methods and systemic approaches were required, and that capabilities needed to be developed to implement and utilise such TA. Although there were some exceptions, most developing countries shared a need to build several key capabilities:

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[60] The policy impact of TA and TF is often difficult to trace. Evaluations of such impacts are rare, and the recommendations that arise from these exercises are frequently just one part of a larger wave of proposals emerging around the same time. In fact, the focus of TA/TF on a particular topic often mirrors a broader upsurge of interest. Without follow-up to assess the impact of TA/TF initiatives, opportunities to learn valuable lessons from these projects are lost.

- Capacity in TA and TF methodologies (especially the newer methodologies) are often lacking; pooling resources between countries may, where appropriate, enable more effective activities.
- Internet infrastructures that can reliably support virtual collaboration, nationally and internationally, need to be developed.
- Available statistics required for TA/TF need to be created, and new types of data and data analysis should be accessed.
- Public understanding of STI should be improved, and those communicating with citizens should adopt language appropriate for them to engage in technology-related debate.
- Capacity to act on TA outputs and subsequent political decisions is important; here. Multi-stakeholder TA/TF approaches generate tacit learning within the innovation system that can help to build its resilience and forward-looking activity,

While much of this diagnosis remains valid a decade later, there have been various positive developments. National and subnational TA/TF activities have emerged from within developing countries, along with international networking and the building and institutionalization of capacities to undertake and utilise TA/TF work in many developing regions. One hopeful sign is the formation of the Next Generation Foresight Practitioners (NGFP), a network of over 600 young changemakers from more than 80 countries across six continents.[61] This network fosters the exchange of experience and knowledge through regional and sectoral hubs, such as the Balkan and Middle East and North Africa (MENA) hubs, along with a vibrant African regional network (some of which will be discussed further below).

Before outlining the developments and experiences in three major regions—Africa, Asia-Pacific, and Latin America and the Caribbean—it is essential to briefly discuss regional initiatives. These initiatives play a critical role in building capacities, sharing knowledge about good practices (both generally and within regional contexts), and creating opportunities for collaboration through data sharing and other resources.

Cross-Border TA/TF Initiatives

Over the past few decades, various regional initiatives have been established 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.

In Latin America and the Caribbean, the Economic Commission for Latin America and the Caribbean (ECLAC) has been instrumental in integrating foresight into regional development strategies. A recent report by ECLAC in 2023 on "territorial foresight" highlights the diverse range of foresight activities undertaken, particularly by subnational

[61] For more information, see the Next Generation Foresight Practitioners Network at https://nextgenforesight.org/

agencies (UN ECLAC, 2023). This report emphasizes the critical role of foresight in implementing the 2030 Agenda for Sustainable Development by enhancing strategic planning and enabling the examination of multiple plausible futures. ECLAC advocates for the involvement of various stakeholders to ensure inclusive and comprehensive foresight processes, addressing challenges such as participation barriers, polarization, and the need for strategic long-term planning.

The ECLAC report (2023) outlined steps useful for undertaking such exercises and integrating Foresight into planning for pursuance of sustainable development. Vital intelligence for strategic policymaking and management is provided through anticipatory analysis of emerging trends and other phenomena which can impact the 2030 Agenda goals. Policymakers are thus better prepared to confront uncertainty and turbulence, and to adopt flexible and innovative approaches that can be transformative in the right context. Among the Success Factors that supported production and use of TF for Sustainable Development, were activities that promoted mobilization of municipalities, society, and institutions around common goals to overcome developmental challenges in a changing global context. The report argues for establishing institutional capacities for "anticipatory governance", which implies supporting an "ecosystem" of contributing institutions and not merely establishing appropriate government offices.

An illustrative example of regional foresight exercise in Latin America and the Caribbean is the development of the eLAC2010 Action Plan. Described by Hilbert et al. (2009), this initiative utilized a 5-round Policy Delphi method to support the creation of an action plan for the Information Society in the region. It used online participatory methods and mobilised international expertise, to identify future priorities for inter-governmental negotiation of the 2008–2010 Action Plan. The approach aimed at enhancing the transparency and accountability of policymaking when a resource-scarce region confronts a technology-intensive challenge. The exercise involved multi-agency networking, and was, in effect, a consultation process that refined regional development goals.

At the time, this was the most extensive online participatory policy-making foresight exercise undertaken for intergovernmental purposes in the developing world. The results took the form of a new priority agenda for the period 2008–2010. In 2008, this was the main input for the inter-governmental negotiations in El Salvador, leading to the approval of the eLAC2010 Action Plan. Whether this is considered to be TA, TF, or some hybrid, it is evident that the application of these methods with support from UN agencies proved very influential in shaping regional policy related to ICTs. Similar approaches might well be applicable to many technology-related and sustainable development topics, but there are few examples of such an approach.[62]

The Ibero-American Futurists Network (RIBER) further exemplifies regional collaboration by connecting Latin American countries with Portugal and Spain as part of the global Millennium Project. RIBER has conducted numerous Delphi studies and scenario analyses, contributing to capacity development in foresight and technology assessment across the region. These efforts have enhanced the ability of member countries to anticipate and plan for future technological and societal changes.

In South-East Asia, substantial work has been undertaken in the present century among ASEAN countries.[63] The ASEAN Foresight Alliance (AFA)[64] facilitates evidence-based future planning and helps ASEAN countries develop national policies and strategies. It enhances collaboration, supports investment in education, and raises policymakers' awareness, particularly on environmental sustainability. AFA recently submitted its first report on foresight for the ASEAN Science, Technology, and Innovation Ecosystem to the ASEAN Committee on Science, Technology, and Innovation (COSTI) for consideration. AFA also seeks partnerships with the private sector, research institutions, and international organizations to advocate for the report.[65]

Meanwhile, the Asia Pacific Futures Network (APFN) provides a platform for promoting Futures Thinking and Strategic Foresight across the extensive region. Established in 1999 and supported by the Thai government, the APEC Centre for Technology Foresight (CTF) [66] offers foresight services and workshops on topics like net-zero emissions and the circular economy. [67]

Furthermore, the BRICS nations (Brazil, Russia, India, China, South Africa, Iran, Egypt, Ethiopia, Saudi Arabia, and the United Arab Emirates) have demonstrated a strong demand for foresight and technology assessment capabilities. These countries are actively seeking to develop and enhance their capacities in these areas, leveraging existing frameworks to support capacity-building efforts across different developing regions.

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[62] The use of policy Delphis in developing countries seems fairly limited. Two TA examples are a South African examination of priorities for rural health care, and a case involving Malaysian energy business strategies.

[63] APEC membership, of course, includes some developed countries and Latin American countries, as well as developing countries in South-East Asia.

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

[65] Based on a contribution from the Philippines to the CSTD.

[66] For more information, visit https://www.asiapacificfutures.net/

[67] For a review of other Asia-Pacific networks and initiatives, see Cruz and Moura (2023).

In Africa, the AI4D Africa programme stands out as a targeted initiative aimed at developing long-term agendas for artificial intelligence that respect and integrate African identities and aspirations. Supported by Canada's International Development Research Centre (IDRC) and Sweden's International Development Cooperation Agency (SIDA), AI4D Africa has undertaken comprehensive activities including literature reviews, horizon scanning, participatory workshops, and scenario development. These efforts have culminated in strategic roadmaps for AI development, addressing challenges such as preserving African identity, bridging technology gaps, and fostering inclusive and responsible AI. The programme has significantly enhanced foresight capabilities, equipping policymakers with the skills and understanding needed to shape an inclusive AI future for sub-Saharan Africa.

Beyond regional organizations, thematic and sector-specific bodies also play crucial roles in advancing TF and TA. 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)[68] and the International Maritime Organization (IMO)[69] 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. The United Nations Development Programme (UNDP) works with many developing countries (e.g., Belize) to support foresight capacities and futures literature.[70]

The UNESCO Chair for Future Studies is a notable initiative that has been developing for several years.[71] It is an interesting approach for raising awareness and fostering both public and scholarly interest in future studies, particularly in developing countries. More than 50 chairs have been created under this program, which could be valuable for capacity building. However, in relation to TA and TF, there are some limitations. One issue is the lack of a solid, standardized methodology across the chairs, which can lead to inconsistencies in approaches and outcomes. Additionally, not all chairs maintain a focus on technology and science. Only a few specifically address these areas. Despite these challenges, the initiative's success in stimulating future-oriented thinking, or "futures literacy," presents an opportunity to enhance efforts in TA and TF by leveraging this foundational interest and expertise.

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[68] 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

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

[70] Contribution from the Government of Belize.

[71] For additional insights, visit UNESCO's Futures Literacy page at https://www.unesco.org/en/futures-literacy

UNESCO's Global Futures Literacy Network[72] further exemplifies UNESCO's commitment to advancing foresight activities. This diverse community comprises futures researchers, practitioners, and supporters, including UNESCO Chairs in Futures Studies and Futures Literacy, as well as members of the High-Level Committee on Programmes (HLCP) Foresight Network.[73] The network spans academic and government institutions, businesses, and non-governmental organizations (NGOs) across the globe. Its primary objective is to share design practices, resources, ongoing projects, and progress updates to advance Futures Literacy worldwide. By facilitating the exchange of knowledge and best practices, the Global Futures Literacy Network enhances the capacity of its members to engage in effective TA and TF activities.

The United Nations plays a pivotal role in stimulating regional cooperation and engaging international experts to enhance TA and TF activities.[74] Involving international experts is crucial, not only for their experience but also to provide an external perspective. In many countries, especially developing ones, there can be scepticism toward national experts. An external viewpoint from foreign experts can help build trust and credibility with local governments.[75] Furthermore, managing the quality and reliability of information at the global level is essential. For instance, during the early months of the COVID-19 pandemic, there were 29,000 publications on the topic. Many of these were based on preliminary data and hypotheses, which sometimes led to overwhelming but unreliable information. Ensuring that technology and research are based on credible, well-vetted sources is crucial to avoid the pitfalls of misinformation and to maintain the integrity of scientific discourse.

Engaging developing nations in TA/TF activities is highly beneficial for their pursuit of the SDGs. Leveraging a robust network to support and disseminate best practices and diverse experiences can significantly aid in building these capacities. This support can take the form of organizing training courses, publishing resources, and creating dedicated websites to share knowledge and best practices. Although funding for such initiatives is often limited, it remains essential. The Committee on Science, Technology and Development (CSTD) recognizes the strong demand for information and training, particularly among developing nations, which are eager to develop their capabilities in this area. By utilizing this framework, we can support capacity-building efforts across various developing countries. Exploring diverse opportunities to enhance TA and TF

[72] Ibid.
[73] For more information, visit the UN High-Level Committee on Programmes (HLCP) at https://unsceb.org/high-level-committee-programmes-hlcp
[74] For additional details, visit the UN Futures Lab at https://un-futureslab.org/
[75] Though it is also important to avoid appearing to be patronizing to "lagging" countries, and consider arguments from a postcolonial perspective.

globally is crucial, often involving the expansion of existing capacities and the dissemination of knowledge to support development in different regions worldwide.

We now turn to experiences in different countries, where regional initiatives have already played significant roles in some cases. We will consider countries based on their affiliation with one of three regions: Africa, Asia-Pacific, and Latin America and the Caribbean.

African Experiences with TA and TF for Sustainable Development

In Africa, TA/TF are emerging fields essential for guiding sustainable development and economic diversification. Based on the evidence from documented exercises, the adoption of these tools in the region lags that found in other developing regions. While still in their infancy across the continent, several recent initiatives documented in countries like Botswana, South Africa, Seychelles, and Zambia indicate that interest has grown in the continent during the past decade. South Africa in particular has demonstrated limited but growing experience in both TA and TF, primarily within sectors such as energy, biotechnology, nanotechnology, and health. The National Advisory Council on Innovation (NACI) sponsored and led a large national ForSTI exercise that influenced South Africa's Decadal Plan for STI.

Relatively few TA and TF exercises have been conducted in African countries as part of STI policy planning and implementation. The political culture in some African 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. In such cases, adopting TF could help to promote a culture of longer-term visions and planning time horizons among policymakers.

Despite this nascent stage of adoption in most African countries, there are two notable exceptions where TA has made some strides: Environmental Impact Assessments (EIAs) and health-related TA (Ouma-Mugabe et al., 2024). These areas, while still not central to the broader focus of the current report, demonstrate some progress. EIAs typically concentrate on the environmental consequences of technologies or investment projects and are usually conducted by national environmental protection agencies. This process often operates with minimal coordination with STI policymaking frameworks.

The implementation and governance of EIAs in most African countries have become more participatory, driven by existing legislation and the active involvement of citizen groups and environmental activists. In stark contrast, STI policy lacks similar levels of engagement, hindered by limited civil constituencies, budget constraints, and weak institutional, particularly executive, leadership. On the other hand, health TA in Africa tends to focus narrowly on evaluating the side effects, risks, costs, and benefits of medicines, drugs, and other health technologies. This approach often overlooks broader societal issues and does not integrate with wider STI policies.

For African countries to effectively steer Foreign Direct Investment (FDI) and technology transfer towards sustainable development, there is an urgent need to develop comprehensive TA capacities. Essential strategies for building this capacity include raising awareness about the importance and methodologies of TA, facilitating information exchange and experience sharing among stakeholders, mobilizing and enhancing the skills of individuals involved in TA activities, strengthening institutional coordination, and fostering synergies across different sectors. Additionally, improving policy and legislative frameworks is crucial to support robust TA initiatives.

A key component of advancing these efforts is the establishment of a network of African TA practitioners and institutions. Such a network would promote collaboration, enhance the sharing of good or best practices, and bolster the overall effectiveness of TA efforts across the continent. By addressing these key areas, African countries can lay a stronger foundation for integrating TA into their policymaking processes, thereby ensuring that technological advances contribute meaningfully to the SDGs.

In order to introduce TA on a pilot basis to African countries, UN Trade and Development (UNCTAD) launched in 2021 a pilot project entitled *Technology assessment in the energy and agricultural sectors in Africa to accelerate progress on Science, Technology and Innovation* with three national pilot TAs in Seychelles, South Africa and Zambia (UNCTAD, 2024b, 2024a, 2024d).[76] The project directly addressed the weakness of capabilities in target countries to assess the socio-economic and environmental implications of new and emerging technologies in the energy and agricultural sectors, so that their benefits can be harnessed and their potentially negative effects minimized. STI policymakers and other stakeholders were supported in the design and implementation of a TA exercise in these sectors, which can play an important role as catalysts of sustainable development.

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 uses 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. It aims to encourage a participatory process involving a wide range of relevant

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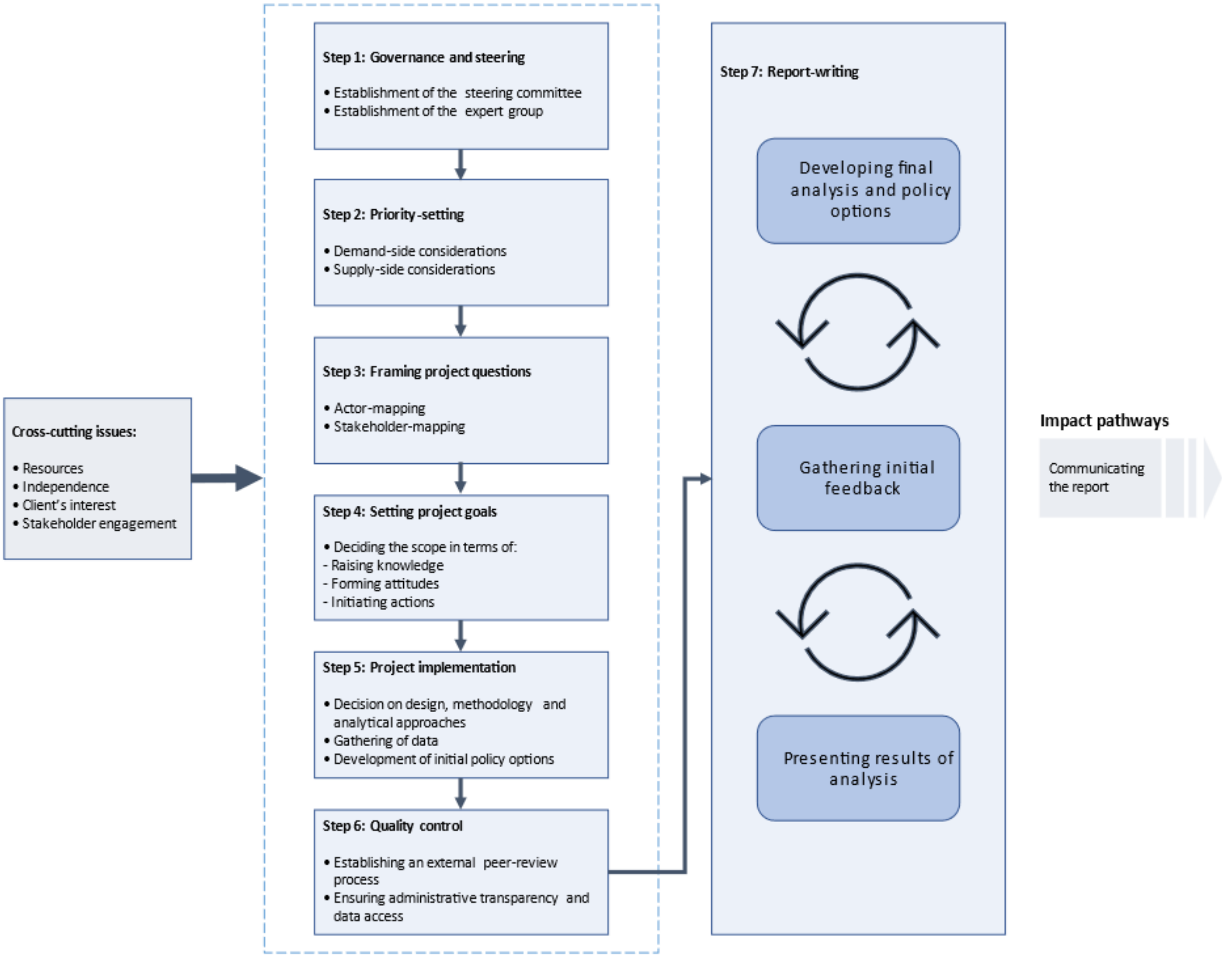
[76] The project responded to the ECOSOC Resolution on Science, Technology and Innovation for Development E/RES/2018/29, encouraging countries to undertake TA exercises as a process for structured debates around new technologies, while also encouraging the CSTD and UN Trade and Development to explore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

stakeholders. It also includes consideration of specific impacts of technology adoption on women, youth and marginalized groups in society. The goals are to generate policy recommendations for relevant authorities, and to help countries improve their capacity to use these policy tools and thus harness the benefits of technologies as well as mitigate their potentially negative effects.

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



Source: UNCTAD

The project advocates for a broadening out of inputs to technology assessment by incorporating citizen and decision-maker participation with technical expertise, and an opening up of political debate about the implications of technological change, going beyond narrow technical or accounting exercises to assess the socio-economic and environmental implications of technologies for SDG-relevant challenges. It focused on energy and agriculture as two sectors of key importance. Each exercise was led at the national level, in collaboration with UN Trade and Development (UNCTAD), including support by consultants, and governed by a dual structure of a national steering committee and national expert group. All three countries selected a renewable energy technology to assess, based on national discussions (agrivoltaics in Seychelles, biogas in Zambia and electrolysers for green hydrogen production in South Africa). In all three cases challenges were encountered given the complex nature of TA, and the need to develop both human and institutional capacities for participatory TA (**Box 4**).

Box 4. The cases of Technology Assessment in African Countries

Seychelles

In Seychelles, the pilot Technology Assessment (TA) was coordinated by the Ministry of Investment, Entrepreneurship, and Industry (MIEI). This initiative was governed by a high-level national steering committee and an expert group, which conducted the assessment with support from both national and international consultants in collaboration with staff from the United Nations Conference on Trade and Development (UNCTAD). The process adhered to the UNCTAD TA methodology, culminating in a report that assessed agrivoltaics for controlled-environment crop production (ACE). Given that agrivoltaics was entirely new to Seychelles, the assessment extensively utilized international scientific and empirical literature to evaluate its potential impacts. This TA report marked a significant step towards integrating photovoltaic (PV) technology into agriculture, aligning with the country's objectives outlined in the National Development Strategy 2019–2023. The report identified a range of potential technological, economic, social, and cultural impacts, with particular emphasis on how the technology could affect vulnerable groups such as women and low-income farming communities, who face significant funding challenges. Additionally, the report provided a set of policy recommendations to facilitate the successful implementation of agrivoltaics in Seychelles. However, the implementation of the methodology encountered several challenges, including the effective functioning of the dual governance structure. Project implementation necessitated considerable local learning-by-doing as part of the pilot nature of the exercise.

Zambia

In Zambia, the pilot TA was overseen by the Ministry of Technology and Science (MOTS) and governed by a high-level steering committee and an expert group. This assessment was conducted with support from both national and international consultants, in collaboration with UNCTAD staff. The evaluation benefited from collaboration with Zambia's Ministry of Energy, which selected small-scale biogas production as the focus technology due to the country's energy challenges. While biogas technology is well-established in developed countries, it remains relatively new in Zambia and has yet to gain widespread public awareness. Leveraging the more advanced maturity of biogas technology and existing experiences in the country made it easier to assess its impacts compared to other pilot projects. Utilizing the UNCTAD TA methodology, the assessment concluded that farm and household biogas can significantly enhance access to basic services such as cooking and lighting, diversify the energy mix, and provide a cleaner, more sustainable energy source. The TA report offered ten policy recommendations aimed at scaling up biogas use in Zambia. Similar to Seychelles, the Zambian pilot faced challenges related to the dual governance structure and required substantial local adaptation and learning throughout the TA process.

South Africa

In South Africa, the pilot Technology Assessment (TA) was led by the Department of Science and Innovation (DSI) and overseen by a national steering committee. An expert group, supported by national and international consultants and UNCTAD staff, focused on electrolyser technologies to advance green hydrogen energy. Over the past decade, the government has established various policies and programs to promote green hydrogen production. The assessment utilized a literature review, research trend analysis, surveys, interviews, and focus groups. The pilot TA report highlighted South Africa's strong technical potential for electrolyser technologies but emphasized the need for better coordination, increased public-private partnerships, and a clearer understanding of economic competitiveness in global markets. Additionally, limited deployment of electrolysers in the country necessitates further study of their social and environmental impacts, which were not easy to establish given the early stage of maturity of this technology. Challenges included operationalizing a dual governance structure, achieving sufficient stakeholder consultation and building an evidence base for the defined technology focus. A key recommendation was to institutionalize TA in South Africa, which is under consideration. To date, existing TA capacity and activity in the country remains mainly university based. Previous TA-like initiatives include two biotechnology-related TA experiments: one informing the National Biotechnology Strategy (2001) through an expert committee, and the Public Understanding of Biotechnology (PUB) program (2003) aimed at raising public awareness and fostering dialogue on biotechnology's implications. Although the PUB program became less active after the National Bioeconomy Strategy (2016), these efforts highlighted the importance of multi-stakeholder engagement and public understanding in managing emerging technologies.

TF projects in STI planning have been documented in Botswana and South Africa.[77] The most elaborate exercise in the region was undertaken in South Africa.[78] The South African National Research and Technology Foresight project was undertaken in the course of a programme of review and reformation of the country's STI system, as described in *South Africa Foresight Exercise For Science, Technology And Innovation – 2030*, published by the National Advisory Council on Innovation in 2020.[79] Throughout this exercise, a diverse range of stakeholders were consulted, utilizing interviews for those unable to attend workshops. Additionally, comprehensive big data analyses were conducted by Russian scholars from the Higher School of Economics, providing valuable insights to support the assessment.

The outputs of this TF exercise were utilized in the development of the Decadal Plan for STI, aligning it with the National Development Plan. This plan specifies areas of focus and the development of STI policies and programs over the next ten years. The results of the exercise and the experiences of its participants were also intended to have a broader impact across various sectors and organizations in South Africa. Additionally, the work is reported to have influenced a significant vaccine programme, which proved vital during a time of crisis and pandemic. One cautionary note about the exercise is that the time horizon considered was rather short, although some efforts were made to extend the vision prior to scenario development. A more extensive horizon could have allowed for the examination of more farsighted and visionary STI initiatives. This suggests that focusing primarily on the near- or medium-term may underplay the potential for more transformative actions.

The second documented TF case is that of Botswana, in relation to which UNCTAD published both the *Botswana Science, Technology and Innovation Policy Review* and the related *Botswana Science, Technology and Innovation Foresight* in 2023 (UNCTAD, 2023).[80] This foresight exercise was part of the STI policy review process, responding to

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[77] 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

[78] Some main points concerning this country's main STI Foresight exercise (SAForSTI) have been summarized above.

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

[80] For further details, see the report at https://unctad.org/system/files/official-document/dtltikd2023d1_en.pdf

the need for increased prioritization in STI found during the review process. Conducted primarily in 2022 amidst COVID-19 restrictions, the exercise relied on online engagements and involved a diverse range of stakeholders, including government officials, parastatal organizations, higher education institutions, and business representatives.

Utilizing a bespoke methodology, the Botswana foresight aimed to create a rapid foresight approach. A significant outcome of the foresight exercise was the creation of five future scenarios, each presented in narrative form to illustrate different potential landscapes for STI development. Four of these scenarios ("Unsustainable," "Vacillation," "Survival," and "Thrive") were based on varying developmental directions characterized by the presence or absence of control and differing levels of uncertainty and risk. The fifth scenario, "Desertification," served as a wild card, representing an unpredictable element that could influence future STI priorities. These scenarios provided a comprehensive view of the possible futures within which Botswana's STI priorities might evolve.

The resulting STI Foresight Report integrated and summarized the findings, offering detailed information on both local and international trends, as well as the prioritized STI domains. The report emphasized the necessity of policy coherence to align STI efforts with Botswana's Vision 2036 and Sustainable Development goals. It recommended establishing a national foresight platform, initiating ongoing foresight projects, and promoting the use of foresight results to foster a sustainable foresight culture. This culture should involve a broader range of stakeholders, including private businesses, SMEs, and civil society, to ensure that diverse perspectives are incorporated into strategic planning.

TA and TF for Sustainable Development in the Asia-Pacific Region

Case Studies in the Region: TA

Many countries in the Asia-Pacific region have undertaken TF exercises, and in some cases, these are well-established and institutionalized. In contrast, reports of TA are less prominent, although several countries reported in response to the CSTD questionnaire having conducted TA exercises.

Srinivas and van Est (2023) also see TA as largely absent, or at best weakly institutionalized in the region, though they do enumerate a number of both governmental and nonofficial Technology Assessment and TA-related activities in India. They note that the Technology Information, Forecasting and Assessment Council (TIFAC) is mandated to conduct technology forecasting and assessment. Its approach is expert-driven and technology-oriented. It is concerned with India's global competitiveness and sustainable development. Much analysis includes technology forecasting and examination of alternative technologies. Studies consider such aspects of the innovation chain as commercialization and upgrading, technology readiness and reliance upon imports, and they take up sectoral issues and economic and societal benefits.

Work includes examination of technologies for climate change mitigation (and adaptation) across ten key sectors. *Technology Vision 2035* assessed technologies in terms of technology readiness levels and contribution to societal needs, and *Technology Vision 2047* is under preparation. Overall, the work on emerging technologies is closer to forecasting (often in the medium-term) than to shorter-term TA. At the time of preparing this report, TIFAC's website features, among its recent publications, a study forecasting penetration of electric two-wheeled vehicles in India, an evaluation of technologies for adding value to seaweed (its production, harvesting and use), an examination of trends in telemedicine in the country, work on greenhouse gases and air pollution in cities, and a technology roadmap for water (*Water 2035*).

Water 2035 involved analysis of water availability and demand projections, along with identifying interventions and underlying technologies required for water security. Brainstorming meetings and a consultative process generated ideas and specified short, medium, and long-term thrust areas for R&D. These included: remote sensing of water reserves; smart sensing for quality; energy-efficient desalination; precision agriculture, effluent and flood management; and real-time decision making capable of tackling threats to water bodies, climate change aberrations, and natural calamities. A wide swathe of emerging technologies is also presented, which need to be proven on the ground, scaled up, comparatively assessed for robustness and cost-effectiveness, and improved upon further, with the aim of raising public awareness and encouraging industry to partner with public institutions in realising nascent solutions.[81]

TIFAC appears to be the closest to an institutionalized Technology Assessment (TA) body in India. Additionally, the Indian Council of Agricultural Research has undertaken work on the adaptation and adoption of agricultural technologies, including a gender assessment that explores ways to alleviate drudgery for female farm workers. While Srinivas and van Est highlight some more participatory TA efforts, these are primarily bottom-up initiatives driven by civil society movements. The main governmental participatory TA activity to date is Bt brinjal, which examined issues surrounding genetically modified aubergine plants. This public consultation effort was a response to the controversy over introducing genetically modified organisms (GMOs) into agriculture. The significant negative sentiment led to a moratorium on the use of this GMO in 2010, although research and development into applications of the underlying technology continued. India stands out in the region for its range of TA-like activities, although there are likely to be fewer well-documented cases elsewhere.

Case Studies in the Region: TF

Several countries in this region have displayed rapid economic growth and become sources of advanced STI in their own right. China, Japan and the Republic of Korea are all

[81] TIFAC (2023) outlines many activities recently undertaken.

examples of this; all have undertaken numerous TF exercises and taken STI policy very seriously. Japan was a pioneer in Technology Foresight, and its use of Delphi and other methods inspired much of the practice adopted (and adapted) in Europe at the end of the twentieth century.[82] 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). These surveys aim at gaining insight into science and technology and the future they will bring about, and at providing evidence for contributing to the consideration of STI policies and strategies.[83]

China has now moved from catch-up in many critical domains of STI, to being among the global leaders (for example, in low-cost solar panels and electric vehicles). Following earlier forecasting activities, China launched major TF exercises early in the present century, featuring large-scale Delphi surveys, scenario-building workshops, deskwork that benchmarked technology performance across countries, and so on. These exercises fed into the 5-year national STI plans. Further work included roadmapping and analysis of bibliometric and other data. Li et al. (2017) considered that TF had reached a stage of maturity in China, with a foresight culture being well-established. A recent review of TF activities in China and Japan reveals that both countries employ similar methodological approaches. However, while both countries address comparable domains, China primarily focuses on engineering-related STI, whereas Japan also emphasizes basic research (Minghui et al., 2022).[84] Although the authors do not use the term "foresight culture," they note that TF is integrated into national, regional, organizational, and enterprise-level activities. Furthermore, the increasing demand for TF is likely to lead to the development of dedicated TF platforms to support decision-makers.

TF has been institutionalised to different degrees across the region. India's extensive STI culture makes it more likely that TF work will be undertaken there,[85] with new actors appearing in the field such as the Centre for Technology Foresight and Policy at the Institute of Technology in Jodhpur. The national government's long-established autonomous organisation, TIFAC has already been mentioned as undertaking TF and roadmapping. Its *Technology Vision 2047* aims at fostering technology independence for a "self-reliant and climate resilient developed India". This has been kicked off with brainstorming and similar activities in a series of regional workshops, in collaboration with HEIs, research institutes and industry. Innovative approaches to gather ideas and examine public responses have also been built into the process, including student

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[82] 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.
[83] Contribution from the Government of Japan.
[84] For a Chinese Academy of Science exploration of the use of online tools and data analytics to move beyond Delphi, see Zhang and Huang (2020).
[85] Contribution from the Government of India.

competitions and an exhibition booth where ideas about India in 2047, and the scope for technological transformation, were displayed and discussed. Stakeholder workshops have been held with representatives of numerous socio-economic sectors, in relation to initiatives around climate change, such as development of roadmaps for decarbonisation of key industries.

Many TIFAC studies are labelled as Foresight, covering a wide range of topics such as “Climate-Smart Agriculture”, food processing and telemedicine. These typically involve interviews and surveys with key actors, and results of analyses are presented to, and validation by, workshops and conferences including experts and stakeholders. In contrast the study on electric two-wheeled vehicles is more a matter of forecasting, even if it features innovative agent-based modelling, and examines uptake of the technology under different scenarios. TIFAC tends to focus on shorter rather than longer term foresight.[86] They also pointed to the importance of demonstration studies, as a way of informing policymakers about technology options; and that of involving key stakeholders from the outset of foresight exercises. TIFAC also offers TF training, including in Delphi and scenario methodology. It should be noted that TIFAC is active in many areas of STI support, including IPR and related themes.

Several smaller countries have established their own longstanding units to conduct and promote TF and related activities. Two of these are the Malaysian Industry-Government Group for High Technology (MIGHT), which hosts the myForesight national-level Foresight Institute;[87] and Singapore’s Centre for Strategic Futures (CSF), part of a Strategy Group in the Prime Minister’s Office.[88]

Malaysia’s myForesight was established in 2012, to apply Foresight methodologies and initiatives related to new technology frontiers for the nation. This was not a completely new activity, since technology mapping and analyses of promising areas for technology and industrial development date back practically to MIGHT’s creation in the early 1990s. MIGHT describes itself as conducting market intelligence, TF and roadmapping and as undertaking policy interventions across a wide range of industries and technologies. It features over 100 members and partners from industry, government and academia. By having prominent private sector personalities and the Science Advisor to the Prime Minister on its Board of Directors, its work has policy impact.

Singapore’s CSF was established in 2009 as a futures think tank within a strategy group derived from their Scenario Planning office, originally set up in 1995 to develop scenarios from a whole-of-government perspective. It was later renamed to reflect strengthened

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

[87] For more information, visit MyForesight at https://www.myforesight.my/ or MIGHT’s official website at https://might.org.my/

[88] For additional information, visit the Centre for Strategic Futures (CSF) at https://www.csf.gov.sg/

links between foresight work and strategy formulation. Its location near the heart of government helps it achieve policy impact from its work.

The two groups have a similar orientation towards medium- and long-term futures, and in linkage of their expertise to national government. myForesight generally appears to have a stronger focus on TF and innovation, and operates with a good deal of industry collaboration. The CSF typically covers a broader range of aspects of governance and national strategy. Both organisations undertake horizon-scanning, though the breadth of these horizons may differ. myForesight features much roadmapping, and undertakes Delphi studies. The main impacts are likely to be on specific industries and technologies, with the aim of improving competitiveness and strengthening the NIS. Scenarios seem to play more of a role in CSF, whose impacts are more on promoting a "Whole-of-Government" approach to promote policy coherence and resilience of the country when confronting future challenges. Both organisations publish fairly detailed accounts of their programmes of work and major results.

These two cases suggest something of the variety of ways in which TF can be systematically taken on board by in-house institutionalisation within developing country political systems. Their host countries are middle-income nations actively pursuing high technology development, and the choices made about focus of activities no doubt reflect different national circumstances – both in resources and ambitions. Not all governments will be willing and able to institutionalise TA and TF in this way, and many will still be in a position of needing to rely more on external expertise, while developing their national capabilities.

The Philippines is also considering the establishment of an STI foresight institute, under the Department of Science and Technology, to provide ongoing support 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. It was conducted with inputs from the Centre for Engaged Foresight (a Philippines hub for strategic foresight, established in 2012)[89], and the United States Agency for International Development programme on "Science, Technology, Research and Innovation for Development ". The latter provided TF tools and training for over 80 government officials (who were encouraged to work in multi-agency teams). Though the work of the Centre for Engaged Foresight suggests that a foresight culture was already emerging in the country, this training was deemed

[89] For further details, visit https://engagedforesight.com/

important for enlarging the perspectives and planning capabilities of personnel across four government agencies.[90]

PAGTANAW 2050 underscored the vital role of STI in achieving the SDGs. The main report illustrated how the government and other stakeholders could use the SDGs to benchmark their progress and align with the objectives of PAGTANAW 2050. These connections were explored using established TF methods such as Delphi surveys, SWOT analysis, megatrend analysis, bibliometrics, and scenario construction. Additionally, the initiative incorporated innovative approaches designed to encourage participants to think more imaginatively, addressing the challenge of fostering creative and forward-looking ideas.

Despite the existence of TF and TF-like activities in many organisations in the Philippines, the country is reported to still require capacity-building, access to data and methodological resources, and familiarising policymakers with the application of scenario methods. There are challenges faced in communicating results to stakeholders: effective ways of doing this are required. A point made in relation to TA is that methods need standardising, and even in areas such as health TA, where they may be well-established, rapid technology change may require consideration of novel approaches.

Indonesia is another middle-income country, and also one of the world's largest countries in population terms. There have been a number of small-scale industry and academic ventures in TA and TF, and the White Paper on R&D Programmes 2005-2025 was based on roadmaps for technology development in six focus areas. However, TF approaches have remained relatively unfamiliar, and recently more effort is being made to develop Indonesian capacities. A new TF exercise was undertaken for Indonesia's National Development Planning Agency (Bappenas), aiming to provide insights for formulation of the national long- and mid-term development plan, and to improve government officials' decision-making by the introduction of approaches going beyond simple technology forecasting. This meant the use of scenario planning to examine events, trends and eventually drivers of possible and plausible futures for Indonesia's economic and social circumstances.

Critically, taking alternative and long-term futures into account confronted government officials with a changed culture of planning. Workshops were designed to help build in-house understanding of Foresight as an instrument for policy and decision making, across various parts of government, specifically by supporting the formulation of long and mid-term development policy goals. A four-day workshop took participants through various stages of the Foresight process, with brainstorming, small-group discussions, and role playing (e.g. the roles of experts). The results of this and subsequent workshops

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

were systematized and incorporated into the draft national plan, contributing to its overall vision, and supplying some 5 development targets, 8 agendas, 17 goals, 10 challenges, and 45 development indicators. After further validation and refinement, the plan entered the political arena, for approval by the House of Representatives.

In this case, participants were very engaged and active during the process, learning how to deal with (potential) deadlocks and how to recognise and manage the biases that facilitators, as well as stakeholders, might bring to the project. A challenge common to many TA/TF exercises involved how best to recruit Delphi experts and other participants and how to ensure inclusivity and balance across stakeholder interests. A second concern was that TF can be resource-intensive and require considerable time. The possibilities for accelerating the process and using methods such as surveys and big data analytics should be explored.

As exemplified in the Indonesian case, the establishment of an internal capability for conducting foresight exercises within governmental organisations represents a strategic investment with long-term benefits. Governments are empowered to take proactive measures in order to effectively tackle intricate difficulties, capitalise on favourable circumstances, and strengthen their ability to adapt and withstand adversity. By adhering to these prescribed procedures and cultivating an environment that values the ability to anticipate future events, governmental organisations can strategically position themselves to make decisions that are better informed, more innovative, and adequately prepared for the future, ultimately resulting in benefits for their society.

TA and TF for Sustainable Development in the Latin America and Caribbean Region

Several countries in the region have become active in using TA and TF. The Parliamentary Technical Advisory (ATP) of the Library of the National Congress of Chile was established in 2007 as a technology assessment (TA) institution. ATP conducts expert consultations using the Delphi method to address specific legislative issues. The ATP also engages in extensive networking with the scientific community, collaborating with the National R&D Agency, a consortium of Chilean universities, and international TA organizations. The overarching aim of these efforts is to strengthen the use of scientific evidence in decision-making within the National Congress. By institutionalizing TA approaches and fostering international collaboration, the ATP seeks to democratize knowledge and contribute to sustainable development and improved quality of life. Chile collaborates with other countries in Latin America, including in Argentina and Mexico.

Brazil has had decades of experience with TF. Its current activity is too extensive to fully summarize here. The scale of activity in Brazil is such that there is a complex institutional infrastructure, with many public agencies involved. Major projects often involve collaboration between multiple organisations within and outside of government.

Brazil effectively adapted international methods to its context, utilizing a wide range of approaches from qualitative methods like scenario development and expert panels to quantitative models and future-oriented employer surveys. Despite challenges common in developing countries, such as limited resources and institutional constraints, Brazil managed to develop a strong foresight culture at both the regional and national levels. The alignment of sector foresight for technology, production, occupational, and educational aspects within a single institutional framework is considered best practice. This integration helps address certain institutional deficiencies and serves as a strong example of effective implementation (Bakule et al., 2016, p. 133).

The main player in TF, the Centre for Management and Strategic Studies in STI (CGEE),[91] was established in 2001.[92] It is a nonprofit organisation overseen by the Ministry of STI, which is also responsible for the Funding Authority for Studies and Projects (FINEP) and the National Council for Scientific and Technological Development (CNPq), as well as research centres on advanced technologies in nuclear, space and other fields. CGEE had around 100 staff members in 2021 and interacts with thousands of experts from hundreds of institutions every year. It recently reported having undertaken more than 500 STI-related studies and evaluations, which feature such topics as human resources, sustainability, energy, and innovation indicators. In 2023, survey-based analyses of public perceptions of STI and related issues indicated high levels of concern about climate change, as well as significant inequality in knowledge and the ability to participate in STI decisions across society. In addition to these findings, the Foresight Programme has supported international conferences and various levels of training activities.

Another agency, the Observatory of STI (OCTI), which employs nearly 20 staff members, has two main axes of activity. These include: (1) Panoramas: monitoring the state of the art, trends and themes emerging in the STI environment, identifying challenges and opportunities, formulating and evaluating STI policies and programmes; and (2) developing and analysing STI Indicators to inform public policies in general, to guide the National Innovation Policy, and to enable evaluation of Brazilian STI development and policies in relation to the international context. Many publications featuring STI indicators are produced, with several recent ones focusing on the regional dimension of activities across Brazil. Another body of work uses "semantic network analysis" to map STI publications and examine the contribution of Brazilian researchers to established and emerging areas of scientific study.

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[91] Contribution from the Government of Brazil.
[92] For more information, visit the Centre for Strategic Studies and Management (CGEE) at https://www.cgee.org.br/

CGEE's role in supporting strategic decisions in Brazil's STI policy initially gained prominence through its provision of intelligence services concerning the NIS, particularly in supporting the ENCTI National Strategy in STI. The first ENCTI was launched in 2012, with two further rounds, with the 5th National STI Conference took place in Brasília in June 2024 to support the current ENCTI. CGEE also played a fundamental role in the creation of sectoral innovation funds and has provided technical support for their implementation. Horizon-scanning of technology trends, SDGs, and detailed analysis of Brazilian systems of innovation go into the TF work. Tools such as Delphi surveys and multicriteria analysis have been used for decision support in areas like energy systems

Beyond CGEE, much foresight activity in Brazil is carried out in relation to specific sectors (e.g., agriculture) and functions or goals (e.g., health, workforce development, and training). The Brazilian Agricultural Research Corporation (EMBRAPA), for instance, operates Agropensa,[93] a Strategic Intelligence System that engages in trend analysis and horizon scanning on agriculture-related issues. The megatrends currently under examination include sustainability, adaptation to climate change, technological intensification and production concentration, rapid shifts in consumption and value-added, the biorevolution, integration of knowledge and technologies, and increased governance and risks. These trends have been evaluated by over 300 specialists and leaders in Brazilian agriculture through extensive document analysis, both quantitative and qualitative assessments, and numerous meetings to create a vision for the future of Brazilian agriculture. Earlier work outlined four scenarios for this future, varying based on (a) the development and adoption of frontier R&D, and (b) the extent to which national agricultural production chains focus on traditional agricultural commodities versus engaging in the emerging bioeconomy.

EMBRAPA's work often includes elements of both TA and TF. For example, one study explored the potential impacts of pesticide use patterns on water basin contamination. Additionally, EMBRAPA provides a wide range of STI support, including R&D. Some of its work also involves broader participatory engagement of stakeholders, such as a survey and focus group exercise aimed at understanding rural actors' perspectives on the risks to water and food security posed by local climate change impacts, specifically in the mountainous region of Rio de Janeiro state. 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.

Another Brazilian case focuses on future skill requirements and industrial employment prospects. The National Service for Industrial Training (SENAI)[94] examines prospects for

[93] For more information, visit the AgroPensa platform at https://www.embrapa.br/agropensa
[94] One example of such work is presented at https://www.oitcinterfor.org/sites/default/files/file_publicacion/oit_Prospectiva_ing_sec.pdf

employment and changing occupations, using expert panels and workshops, modelling, Delphi and other methods. These results feed into its training initiatives, aimed at creating a workforce fit for tomorrow's industries. SENAI promotes transfer of its foresight approach, and knowledge of its results, across the region.

Finally, the Oswaldo Cruz Foundation (Fiocruz) is a major actor in many aspects of public health, playing a prominent role in health TA. It also hosts the Center for Strategic Studies (CEE)[95] and runs a major project called "Health Tomorrow", alongside a think tank focused on supporting sustainable development and health. In addition to examining prospects to 2030, recent work has also examined the ageing population. Internal scenario development included studies prior to the COVID-19 pandemic, exploring preparedness for a previously unknown infectious disease, and recent work is exploring ways of horizon-scanning for such disease threats.

Peru's National Centre for Strategic Planning (CEPLAN) led the preparation and dissemination of the *2050 Strategic Plan for National Development* (PEDN), combining long-term foresight with (multi-term) strategic planning. The aim was to drive national medium- and long-term development, while near-term actions could be identified and implemented to progressively advance towards the established targets. Four national strategic objectives have been outlined. The plan was formulated in coordination with government branches, autonomous constitutional bodies, regional and local governments, political parties and civil society organizations, using methodologies for direct participation and opinion polling (e.g. the draft plan was submitted for public consultation and comments).

As is apparent in Peru's response to the CSTD questionnaire these serious TF efforts[96] involve close cooperation with the Institute of Science and Technology Evaluation and Planning (Republic of Korea). A project on "S&T Planning and Technological Forecasting for Prioritised Sectors in Peru" is being undertaken with the aim of capacity-building and supporting strategic planning, and the goal of establishing a TF organisation that will offer such key services as horizon-scanning, technological forecasting exercises every five years to identify emerging technologies with high potential for the country's development), building decennial visions for STI, and providing decision-making support via foresight studies addressing specific issues. Sustainable development is a major goal which requires anticipatory governance, and technology roadmaps, linked to sectors such as agribusiness, advanced manufacturing and creative industries. These are related to several SDGs, especially SDG 9 (Industry, Innovation, and Infrastructure), SDG 8 (Decent Work and Economic Growth) and SDG 13 (Climate Action).

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[95] For more details, visit the Center for Strategic Studies (CEE) at Fiocruz at https://cee.fiocruz.br/
[96] Contribution from the Government of Peru.

Colombia's Technology Foresight Programme (CTFP) represents a rare case including the systematic evaluation of an exercise. Such detailed assessment of TF is not often undertaken, which is one reason why the documentation of impacts from TF has been a challenge. Thus, even though the case dates from the first decade of this century, it is worthy of attention.

As Popper et al. (2010) describe, the Colombian Office of Science and Technology (COLCIENCIAS), in collaboration with government departments and the Development Bank of Latin America (CAF), initiated the CTFP in 2003 with three main objectives. These were to contribute to the development of a national vision for transitioning to a knowledge-based economy, conduct foresight and technology watch (horizon-scanning) exercises in strategic sectors, and build local capacities to undertake foresight and apply its results. One outcome of the CTFP was COLCIENCIAS' decision to further institutionalize these objectives by creating the Colombian Foresight Institute at the Universidad del Valle in Cali. It was determined that achieving both extensive and deep participation in the program would be challenging, as it required more time and resources than were immediately available. As a result, a program of approximately 32 smaller activities was organized, with the majority of these still involving more than 50 participants

Looking ahead to 2020 and beyond, the CTFP conducted numerous studies on specific technologies and industries, employing a variety of foresight techniques, with most studies using more than 10 different methods. The most commonly used techniques were those for horizon scanning, such as bibliometrics, trend extrapolation, and patent analysis. Other techniques included scenarios, brainstorming, stakeholder mapping, key technologies identification, morphological analysis, and relevance trees. 'Productive chain approaches' were applied to explore the interconnections between sectors.

In the second cycle of CTFP work, greater emphasis was placed on identifying research priorities and compiling lists of key technologies for centers of excellence, COLCIENCIAS' STI programs, and various stakeholders. For example, stakeholders were identified in productive chain studies conducted with the Ministry of Agriculture. While there was some international collaboration, considerable attention was also given to the diverse regions within Colombia, including through local workshops.

Often evaluation of TF-type projects mainly consists of surveying or interviewing potential users of the results of the work, in government, industry and elsewhere. They are asked what, if any, influence the results had on their decision-making and broader strategic planning. Sometimes this is supplemented by efforts to assess impacts by "traces" that can be found in policy documents and the like. The Colombian study applied these methods, both for the CTFP as a whole and for some of its subprojects, and also set up an Evaluation Forum, with virtual and face-to-face activities of national and international expert panels who reviewed the views on the exercise that they had produced.

The evaluation report concluded that the CTFP had been largely successful in achieving its three main objectives and provided good value for money. In fact, there was speculation that the budget might have been set too low, although about a third of the projects within the program received additional sponsorship from international organizations. The simultaneous management of multiple projects proved to be a strain on program leaders. The organization of the second cycle placed management and technical decision-making groups within COLCIENCIAS. It increased CTFP's capacity to shape and inform policy processes, though it may have strengthened ties with COLCIENCIAS at the expense of other stakeholder groups.

A majority of the 32 projects were seen as producing novel results, many of which had already been applied to research agendas or policies. The most significant impact of CTFP on public policy was its contribution to the STI Vision 2019, which directly informed the preparation of the National STI Plan 2019. A biotechnology project significantly shaped the policies and research priorities of COLCIENCIAS' National Biotechnology Program. Numerous publications and other outputs were produced, and the evaluation concluded that substantial progress had been made in fostering a broader foresight culture and helping to establish new institutions. However, more follow-up planning could have monitored progress and identified any weak spots. Along with an absence of adequate evaluation, failure to monitor and intervene in the application of results is a weakness of much TA/TF work, especially when carried out by external consultants.

6.2 Initial Questions Posed

Note: this report was asked to cover the following issues:

- How have the ForSTI and TA approaches been useful for countries in planning, priority-setting, design and implementation of national and industry level policies related to research, science, engineering, technology and innovation in countries? How have they been integrated into the planning, priority-setting, design and implementation of STI policy? *Addressed in Sections 2 and 3.*
- What are good practice examples and/or bad practice examples from past experience in different countries? *Addressed in the Sections 2 and 3*
- What can they contribute to policymaking on current important policy issues – such as climate change, net zero emissions, artificial intelligence, industrial policy etc.? *Addressed in the Section 2*
- How does rapid technological change (RTC) affect how they should be implemented and whether they will be either more or less effective? Does RTC require changes in their use? Can they still be useful? *Addressed in the Section 2*
- What is the relationship between ForSTI and TA? Are they clearly delineated and distinct? Do they overlap? Is the distinction between them useful? Can/should they be used together and fed into one another? *Addressed in the Introduction (section 1, and returned to frequently)*
- What have been the main aims of exercises implemented by countries, organizations and firms in different countries? *Addressed in Section 2, and Annex Section 6.1.*
- What is the appropriate level of analysis in using them (national level, industry level, a specific technology or group of technologies, or technological systems) *Addressed in Sections 2 and Annex Section 6.1.*

6.3 The List of Participants in Ad-Hoc Expert Meetings, July-August 2024

Name	Title	Affiliation	Country of residence
Adrian Ely	Reader in Technology and Sustainability	Science Policy Research Unit (SPRU), University of Sussex	United Kingdom of Great Britain and Northern Ireland
Alexander Sokolov	Director	International Research and Educational Foresight Centre, ISSEK, Higher School of Economics (HSE)	Russian Federation
Andrew Curry	Programme Director	School of International Futures (SOIF)	United Kingdom of Great Britain and Northern Ireland
Armin Grunwald	Head	Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe Institute of Technology (KIT)	Germany
David Guston	Professor	Global Futures Laboratory, Arizona State University (ASU)	United States of America
Douglas Robinson	Policy Advisor	Directorate for Science, Technology and Innovation, Organisation for Economic Cooperation and Development (OECD)	France
Erik Fisher	Professor	School for the Future of Innovation in Society, Arizona State University (ASU)	United States of America
Ian Miles	Professor	Alliance Manchester Business School, University of Manchester	United Kingdom of Great Britain and Northern Ireland
Igor Yegorov	Head	Institute for Economics and Forecasting, National Academy of Sciences of Ukraine (NASU)	Ukraine
Jean Eric Aubert	President	French Foresight Society	France
John Mugabe	Professor	Graduate School of Technology Management (GSTM), University of Pretoria	South Africa

Like Yuan	Professor	Institute of S&T Foresight and Statistics, Chinese Academy of Science and Technology for Development (CASTED)	China
Martina von Arx	Project Manager	TA-SWISS	Switzerland
Mlungisi Cele	Head	National Advisory Council on Innovation (NACI)	South Africa
Mohamed Ramadan A. Rezk	Director	Science, Technology and Innovation Observatory (ESTIO)	Egypt
Mohd Nurul Azammi Mohd Nudri	Principal Analyst	Malaysian Industry-Government Group for High Technology (MIGHT)	Malaysia
Niklas Gudowsky-Blatakēs	Researcher	Institute of Technology Assessment (ITA), Austria Academy of Sciences (OeAW)	Austria
Ozcan Saritas	Professor	Rochester Institute of Technology (RIT) in Dubai	United Arab Emirates
Peter Glendey	Director of Futures	School of International Futures (SOIF)	United Kingdom of Great Britain and Northern Ireland
Poonam Pandey	Maria Zambrano Fellow	University of Vigo	Spain
Ralf Lindner	Center Head	Fraunhofer Institute for Systems and Innovation Research ISI	Germany
Rinie van Est	Professor	Rathenau Institute, and Eindhoven University of Technology (TU/e)	Kingdom of the Netherlands
Trudi Lang	Professor	Saïd Business School, University of Oxford	United Kingdom of Great Britain and Northern Ireland
Yanuar Nugroho	SDGs Expert Coordinator	Ministry of National Development Planning	Indonesia

6.4 Suggested Questions for Discussion during the Intersessional Panel of the Commission

- What are the implications of unequal access to TA/TF resources and capabilities, and how can these be mitigated globally?
- What are the most significant barriers to translating TA/TF insights into actionable policy recommendations and strengthening policy uptake of findings and recommendations?
- What governance structures are needed to ensure that TA/TF are effectively integrated into national, regional and global decision-making processes?
- What strategies can be adopted to ensure that TA/TF activities address the unique needs of developing countries?
- How can TA/TF be strategically utilized to guide and accelerate a transformative innovation policy agenda, ensuring that emerging technologies contribute to sustainable development?
- What strategies can be adopted to ensure that TA/TF activities can be harnessed by developing countries for sustainable development?
- How can TA/TF be strategically utilized to guide and accelerate a transformative innovation policy agenda, ensuring that emerging technologies contribute to sustainable development across countries at different levels of development and under diverse national, sub-regional and regional circumstances?

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