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Conceptualizing Technology Governance: An Ecosystem Perspective

Jatin Nathwani and Ann Fitz-Gerald*

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Whereas critical challenges to humanity have been tasking international experts for millennia, rapid advancements in emerging transformative technologies (ETT) give rise to a fundamental problem that requires strategies for risk management and governance. This paper examines the relationship between well-accepted and supported global goals and outcomes, in keeping with the United Nations Sustainable Development Goals (SDGs) and Maslow's hierarchy of needs. It also seeks to define what characterizes a critical ETT ecosystem as the world grapples with ways in which technological creations and applications must be managed, monitored and governed.

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Whereas critical challenges to humanity have been tasking international experts for millennia, rapid advancements in emerging transformative technologies (ETT) give rise to a fundamental problem that requires strategies for risk management and governance. The accelerated pace of technology development has introduced significant and concerning gaps between the widespread adoption and applications of technological advancements and our capacity to manage the outcomes for overall global benefit. Aaron Wildavsky observed that risk is an inevitable concomitant of activities from which benefits are derived and asks: "What should we do when the safe and the dangerous are inextricably intertwined?"[1] In essence, risk and benefit are two faces of the same coin and the creative challenge for decision-makers is to shape the societal capacity to respond resiliently to cope with untoward events.[2] To anticipate and predict on the basis of what is "knowable" is one approach, but resilience through "defence-in-depth," back-up and embedded capacity to recover from the "unpredictable" risks is another strategy.

Recent developments (for example, generative artificial intelligence (AI), biotechnologies, Big Data and digitally driven technologies) require us to address questions concerning whether emerging technologies *should* be made rather than whether they simply *can* be made. William White points to deficiencies in our capacity to manage the danger of a "polycrisis," which he describes as "a simultaneous crisis in many systems that could lead to dangerous, perhaps even uncontrollable, feedback effects that arise from non-linear 'cause-effect' relationships at the intersections of complex systems."[3] A coherent approach to answering these questions signals the need for close collaboration between epistemic communities in both social science/humanities and STEM (science, technology, engineering and mathematics), which have traditionally had little or no collaboration. It also raises the question of how the new ETT "ecosystem" should be defined, its applications and potential benefits and risks evaluated and enumerated, and its oversight and governance deficits developed and structured.

This paper examines the relationship between well-accepted and supported global goals and outcomes, in keeping with the United Nations Sustainable Development Goals (SDGs) and Maslow's hierarchy of needs. It also seeks to define what characterizes a critical ETT ecosystem as the world grapples with ways in which technological creations and applications must be managed, monitored and governed.

Background

Rapid technology advancements now move at a pace that outstrips policy development, and even the education and training requirements supporting their use. Competent young graduates who venture into the offices of Meta, Google and other organizations that base their success on data-driven growth and upscaling, develop their careers in industry and the private sector, which develop corporate policy and accountability frameworks that shape and mould these ideas. Meanwhile, with the world's nations committed to supporting the SDGs, and many countries focused on the delivery of basic public services

[1] Aaron Wildavsky, *Searching for Safety*, Transaction Publishers, New Brunswick, NJ, and London, UK (1988).
[2] Mary Douglas and Aaron Wildavsky, *Risk and Culture*, University of California Press, Berkeley, CA (1982).
[3] William White, *Mitigating Global Warming Is Not Our Only Problem: Are We 'Sleepwalking' Towards a Global Polycrisis?* Global Risk Institute (2023).

and basic individual needs, the very governance organs that lead in the interpretation, evolution and management of the rules-based international order must now contend with the prospects, and the direct risks and threats, that technology advancements pose for the achievement of these widely supported global outcomes.

The safety and security of the individual became the backbone of the UN's 1994 Human Development agenda.[4] It called for the individual, rather than political groups of government, to be the referent object of security assurances of the state. Today, the ability of illicit groups to use data to target the elderly with telephone scamming, and the penetration of computer-based banking systems, threaten individuals in even the most remote and seemingly safe parts of a country. Similarly, cyberattacks launched on critical infrastructure such as hospital systems, power grids and aviation transportation systems can bring the economic activity of a country to a standstill. The onset of such threats, and their impacts, are often referred to as "black swan punches": threats and impacts that cannot be predicted and for which no available policy response exists. Despite the emergence of "new" threat vectors, our primary goal should be to mitigate unanticipated shocks through resilient strategies and improved predictions with a new breed of multidisciplinary knowledge and skillset "nexus" in public policy spheres.

The advent of new threat vectors promulgated by ETT, such as AI and its range of enablers, including large language models (LLM), machine learning, AI co-pilots and rational agents, has introduced a wave of technology-based challenges to the policy community. In the past, such challenges have been nurtured predominantly by the social science and humanities disciplines. This reflects the traditional delivery of international affairs and public policy studies, which has not tended to feature core functions of technology, evaluating their impact on society and, therefore, implications for policy development.

Such a focus also demands a pedagogical transformation in the delivery of policy studies that recognizes the need for multidisciplinary approaches, intellectual bilingualism and critical problem-solving based on the lessons of how technology impacted society in the past, the actions taken as a result, and ways in which these experiences could help inform how we address future challenges. Whereas the advent of the printing press in 1436 temporarily upended the balance between freedoms and responsibilities, as the world has learned more about issues concerning plagiarism, intellectual property, and copyright — contributing to better governance of the impacts and to restoring the balance between freedoms and responsibilities — so too must we now learn about the societal impacts and governance implications of new emergent and potentially disruptive technologies.

In developing ways to address technology's impact on society and desirable global outcomes, it is first necessary to define what we mean by the concept of ETT. According to Rotolo, Hicks and Martin, an emerging technology is a radically novel, rapidly growing innovation that upends previous knowledge and promises to alter interactions among actors and institutions in important socioeconomic spheres.[5] Our

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[4] UNDP (United Nations Development Programme), *Human Development Report 1994: New Dimensions of Human Security*, New York, United Nations Development Programme (1994).
[5] Daniele Rotolo, Diana Hicks and Ben Martin, "What Is an Emerging Technology?", *Research Policy* 44(10), pp. 1827-1843 (2015).

reference to ETT, which includes the additional word "transformative," is not to depart from the 2015 definition but simply to provide scope and parameters characterizing those novel technologies that interact to drive digital transformation processes that produce second- and third-order technology-based outputs.

An Ecosystem View

In the context of the analysis about ETT, we believe that it is critically important to shape, foster and enhance a multi-disciplinary approach to tackling the most important global challenges and to further develop the capacity to manage the complexity of risk across systems. Taking such an approach would help ensure the positive benefits of ETT outweigh harmful consequences for every global citizen. The model presented below characterizes a technology governance ecosystem that impacts on five main global goals (depicted as receptor domains in the outer ring):

1. Improved quality of life
2. Quality education
3. Zero hunger
4. Security and justice
5. Zero carbon

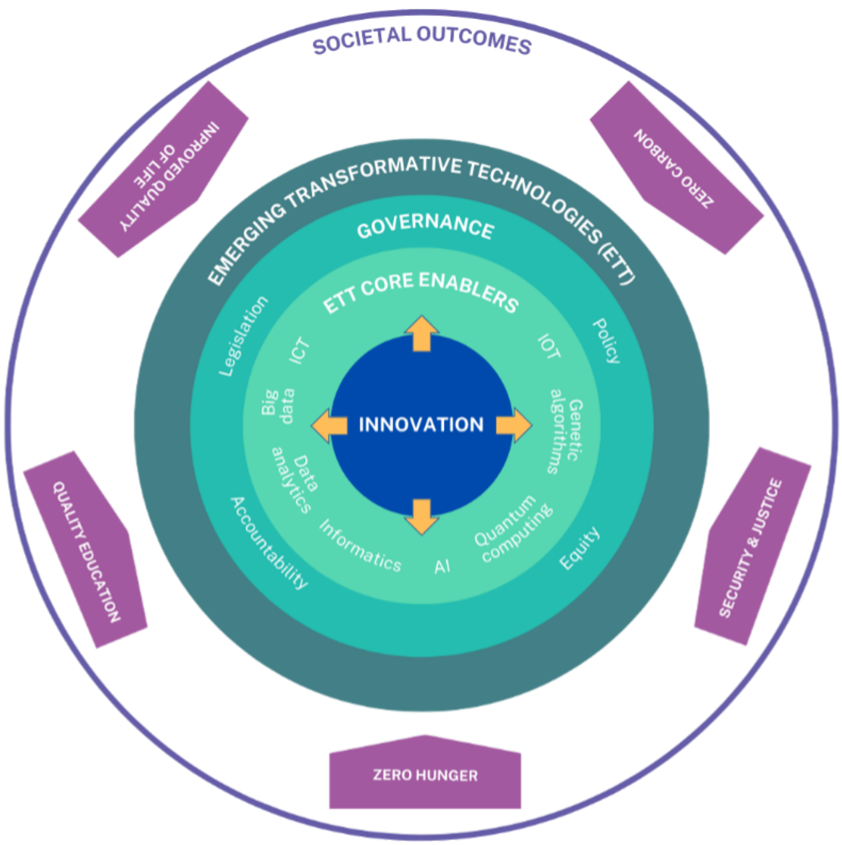

Figure 1: Technology Governance Ecosystem

The presentation of an ecosystem view of technology governance takes into account the scale of the challenge in delivering high-level goals, and also recognizes the risks, benefits, perils and pitfalls along the bumpy journey from idea(s) to tangible outputs. It depicts ways in which effective transition can be achieved through select ETT.

In contrast to future-based scenario designs, we focus on feasible technologies to help answer the question: "What future(s) do we want?" and work backwards to identify those technologies that have the potential to bring about the desired transformative change. The ecosystem view provides a rich perspective that recognizes the importance of interconnectedness and linkages between the receptor outcomes of knowledge creation through quality education, and the need for resilient institutions, security and justice. These, in turn, shape and allow attainment of a higher quality of life, equitable health outcomes, mitigated threats of climate risk and economic disruptions, and more sustainable food security.

The outermost circle could include examples of leading transformative technologies such as, for example, 3-D printing, modular housing, smart energy systems, modular adaptive and decentralized water infrastructure and AI-driven medical diagnostics and therapeutics. We note and emphasize that each technology is an integral part of an ecosystem linked closely to its constituent parts, and its future evolution is subject to forces and stresses from the outside. For example, an energy system will have similarities in its design and organization to the health, transport, food or economic systems. The information and communications technology (ICT) sector, comprising several interrelated links, not only connects and reinforces physical components of the ICT system but also the agents and decision-makers who need reliable and authentic information for delivering specific outcomes.

The innermost circle represents innovation — the ideas and visions that drive the applications and processes — whereas the outermost receptor domains denote the outcomes and ultimate impacts we desire as the positive pathways taken by ETT to produce. Between the idea and the outcome are multidisciplinary, multifaceted and complex pathways that require knowledge, skills and partnerships that reflect the pairing of the creation community (largely STEM) with those who understand the impact that ETT and their applications have on society, and also with those who can develop the appropriate laws, norms and frameworks to guide these creations and applications to positive, low-risk outcomes in support of desirable global goals. Institutional capability must be developed to support the understanding of both lateral interactions within each of the circle layers, and the risks and opportunities of the outward-focused trajectories toward global goals.

Innovation

Innovation sits at the core of global progress and here we recognize both the unpredictable and the power of human reasoning to deliver positive or negative outcomes. Innovation starts with an idea and vision and translates into tangible goods and services with economic value.

For example, the 2001 Draft Human Genome Project empowered research into the genetic roots of human disease and helped to revise the idea of the gene itself.[6] The health sector has also been revolutionized by two innovations: a minimally invasive, robotically driven surgical system supported by console-controlled instruments, under a robotic system that uses stereo camera image streams;[7] and ICT-based interventions that enable patient empowerment.[8] Similarly, the creators who introduced the groundbreaking Covid-19 vaccine are now developing a personalized cancer vaccine, to be ready by 2030, that will protect individuals from around the world against multiple tumour types.[9]

These recent innovations, and many others, seek to contribute to global outcomes and goals. These goals and aspirations become the common language that bridges the STEM communities (who are responsible for the initial creation of the technologies) to the social science and policy communities (who are concerned with the governance, accountability, ethical and legal implications of the technologies). Enabling these conversations at the earliest stages, and evolving innovations through these additional considerations, will ensure that outputs and outcomes have more optimal impacts on global goals.

Classifying ETT

The circle layer that follows the initial innovation encompasses the broad range of ICT, comprising an array of ETT (both hardware and software) that continues to have enormous impacts on today's data-driven and digitally based society. There is not a single sector in our economy untouched by the digital transformation.

As noted by the Council of Canadian Academies:

> The future will be shaped by greater and greater levels of connectivity — connectivity among people, as well as connectivity among objects. Now, everything that can be connected to high-speed broadband has the potential to be smart, and such smart devices are woven together in complex systems that can change how Canadians live, work, and play. The world is on the threshold of fundamental, transformative change — a powerful convergence of digital computing power and information technologies with the physical infrastructures and institutions that deliver energy, water, food, transport, and communication services. This convergence of ICT with the physical world can potentially drive Canada towards significantly better environmental performance, economic productivity, and health and social well-being. In other words, ICT together with physical infrastructure and institutional design can help Canada on the path to

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[6] Alexander J. Gates, Deisy Morselli Gysi, Manolis Kellis and Albert-László Barabási, "A wealth of discovery built on the Human Genome Project—by the numbers," **Nature** 590, pp. 212-215 (2021).
[7] Orhan Özgüner, Ran Hao, Russell C. Jackson, Tom Shkurti, Wyatt Newman and M. Cenk Cavusoglu, *Three-*

International Conference on Robotics and Automation (ICRA), Brisbane, QLD, Australia, pp. 6617-6624 (2018).
[8] Liran Karni, Koustuv Dalal, Mevludin Memedi, Dipak Kalra and Gunnar Oskar Klein, "Information and Communications Technology-Based Interventions Targeting Patient Empowerment: Framework Development," *Journal of Medical Internet Research* 22(8) (2020).
[9] Linda Geddes, "Cancer and heart disease vaccines 'ready by end of the decade'," *The Guardian* (2023).

sustainability. Citizen empowerment — both as consumers and social decision-makers — is a key part of this vision.[10]

Notable recent examples of these ETT include AI, Big Data, the Internet of Things (IoT), quantum computing, data analytics and genetic algorithms driven by advances in data science that enable access to massive data banks connected to sensors, devices and integrated ICT systems. These systems underpin the IoT, a closed-loop system in which a set of sensors is connected to servers via a central network, with the data from the sensors being stored in a database and then analyzed for different "use cases."

It is a well-accepted notion that AI and advanced robotics have impacted the world in a transformational way and the prognosis for the future is unclear. Machine learning and LLMs now serve as replacements for what have traditionally been human-directed and human-managed functions. The role of robotics in manufacturing is already well recognized, with its applications at the scale of end-user in everyday activities still evolving.

Governance Considerations of ETT Applications

During a time when most knowledge of ETT applications sits within the private sector and industry, public policy institutions must generate new partnerships and institutional development practices to draw appropriate knowledge and skillsets around ETT into their organizations. Concerns over the exponential growth of AI-driven technologies mount in the absence of any international consensus on acceptable norms and regulations for AI-based applications. Whereas national governments have waited for geopolitical powers such as the United States and the European Union to take a lead on these issues, sluggish progress — combined with an absence of any global mechanism mandated to lead an ongoing discussion on AI norms and standards — has encouraged nations to move forward in developing their own norms and frameworks. Having different national-based norms and accountability frameworks will significantly impact various forms of multilateral cooperation, including global trade activity, supply chain resilience and management, and international defence cooperation.

The same argument could be said about the IoT more generally. Whereas the internet will never be able to be entirely regulated (nor, some would argue, should it be), norms and regulations underpinning a "gold standard" space on the internet must gradually develop to guide norms for more authentic and trusted content. As with AI, such regulatory frameworks and practices need to be informed by collaborative efforts between government and civil society that also reflect industry and private sector thinking on their own corporate social governance frameworks and some self-regulatory practices.

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[10] Council of Canadian Academies, *Enabling Sustainability in an Interconnected World,* Ottawa, ON: The Expert Panel on the Potential for New and Innovative Uses of Information and Communications Technologies (ICT) for Greening Canada, Council of Canadian Academies (2014).

Technologies

Following the application of interwoven and interrelated governance measures, the potential benefits of ETT-driven technologies will have been evaluated, as well as potential risks enumerated, in terms of how these can directly support desired global outcomes. In this context, ICT have already been integral to smart energy systems as part of intelligent networks. These include: high-efficiency batteries for enabling solar and wind power toward the SDG of zero carbon emissions; precision agriculture/vertical farming for minimizing land use impacts and water, fertilizer and pesticide use toward the SDG of zero hunger; clean water (advanced desalination) for large swathes of the global population; 3D printing and modular design for construction of homes and other buildings; advances in health informatics, therapeutics, diagnostics and surgical processes; and biometrics.

The key point here is that —as indicated by the position of ETT in the outermost circle of the ecosystem model — while ETT emerge and contribute positively to global goals, they remain exposed to ongoing changes in a fluid strategic environment. These changes may bring about countervailing EET-driven technologies that could introduce new risks, or indeed undermine their positive impact on global outcomes. For this reason, a dynamic feedback loop with a strong and interconnected governance system must be maintained.

Figure 2 summarizes the outcomes of the different possible pathways across the technology-governance spectrum. The X-axis represents the consolidated governance capacity with the Y-axis representing data-driven and digital transformation-based innovation supported by ETT. The wavy line representing a direct overall pathway to desired global outcomes also reflects the technology governance literature, which underscores the way in which governance measures consistently "play catch-up" with technology advancements. The upper-left quadrant indicates that innovation driven by ETT in the absence of relevant governance measures reinforces the phenomenon of technology shaping society. On the other hand, as depicted in the bottom-right corner of the diagram, there is the risk of stifling innovation when widespread governance measures on data-driven and digitally transformative technology outcomes are not updated and nuanced to reflect the strategic environment. Whereas these two more extreme results can become the outcomes of pathways taken by an embryonic innovation, in the form of an idea or vision represented by the bottom left-hand corner of the diagram, a well-maintained balance between ETT-driven innovation and effective governance is more likely to positively impact on global goals.

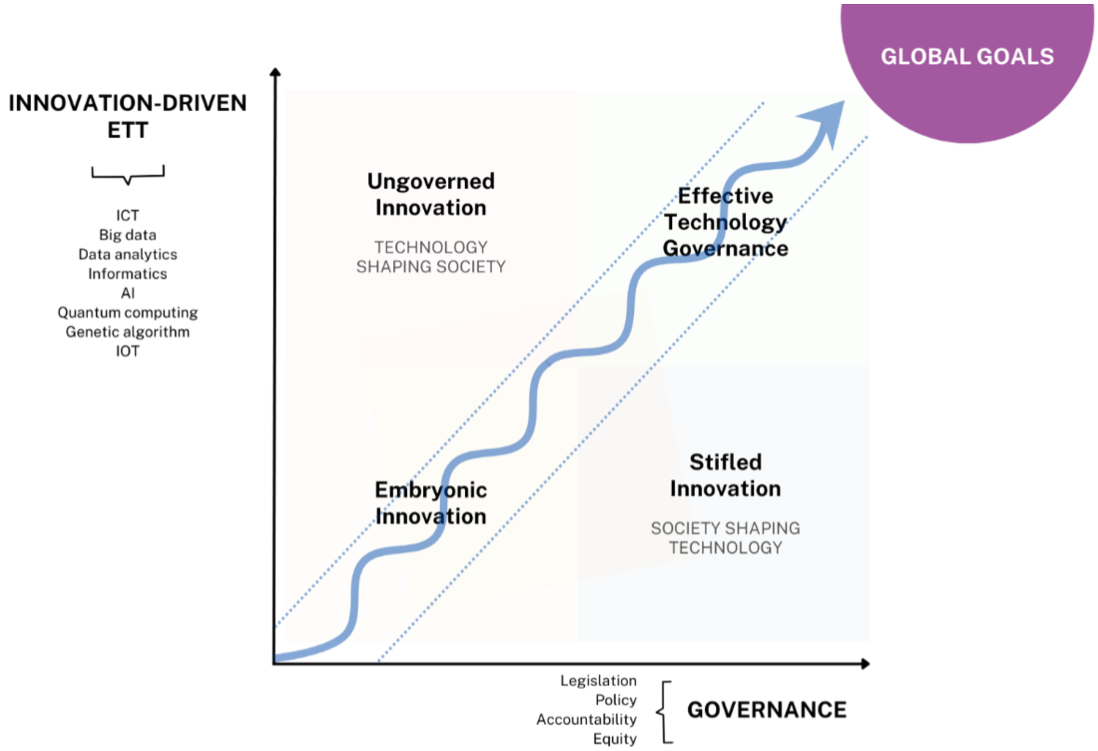

Figure 2. Technology-Governance Matrix

Toward More Effective Technology Governance

Just as more synthesis-based understanding is needed across the various interplay and interactions of ETT, and the way in which they further combine with more conventional forms of technology to form new outputs, a similarly synthesized — or systems-based approach — must also be applied to technology governance. This demands the harmonization of such things as corporate social responsibility practices, laws (privacy, anti-trust, intellectual property, etc.), licensing, and standards. The data-driven and digital transformation processes that drive ETT and their myriad applications must be viewed as a leading domain of national power — similar to policy portfolios such as defence, foreign affairs and health — with great consideration therefore given to its protection, projection, defence and preservation.

Research on these multidisciplinary challenges to technology-driven solutions to global challenges is already advancing. A recent example is a study on water insecurity and the potential contributions of modular, adaptive, and decentralized water infrastructure which, in addition to producing significant benefits for resource-poor communities, may also cause unintended consequences that exacerbate water insecurity if they are unaffordable, disproportionately lead to system disconnection by wealthier users, or reduce household water autonomy.[11] In this context, research bridging the engineering and social sciences

[11] Justin Stoler, Wendy Jepson, Amber Wutich, Carmen A. Velasco, Patrick Thomson, Chad Staddon and Paul Westerhoff, "Modular, adaptive, and decentralised water infrastructure: promises and perils for water justice," *Environmental Sustainability* 57 (2022).

is building evaluative approaches and paradigm shifts that ensure water justice, security, and sustainability under conditions of climate disruption, as well as improving water security more generally.

This paper emphasizes the need for advancing and implementing a technology governance model that requires intellectual bilingualism to break down barriers and remove the mystique from the traditionally divided STEM and social science/humanities communities. Thought leaders, professors, graduate students and mid-senior careerists — who are now expected to both create and manage the opportunities and risks posed by ETT applications — must understand the vernacular and defining features of each of the ETT, as well as the dynamics of their mutual interactions. Developing familiarity with the relevant domains and datasets that underpin these multidisciplinary collectives must be better understood to ensure trust in science, the veracity of primary sources of information and a deeper appreciation of the wider and different contributing perspectives. Lastly, knowledge creation must focus on problem-solving approaches based on the lessons gleaned from historical impacts of innovation on society, and propositions surrounding potential future challenges and the tools and approaches available to manage these challenges. In so doing, more definitive pathways, relatively free from disruption along the way, will encourage innovative visions for ETT interactions and applications to have a greater chance of impacting more positively on human and societal progress.

Ann Fitz-Gerald is the Director of the Balsillie School of International Affairs and a Professor in Wilfrid Laurier University's Political Science Department. She has worked at both at King's College, London University's International Policy Institute, and at Cranfield University, where she was the Director, Defence and Security Leadership. During her time at Cranfield, Ann led the UK-Government funded Global Facilitation Network for Security Sector Reform and Cranfield's Centre for Security Sector Management.

Jatin Nathwani is a Professor and Fellow at the Balsillie School of International Affairs (BSIA), who leads the Research Cluster 'STEM for Global Resilience', and is the Founding Executive Director of the Waterloo Institute for Sustainable Energy, University of Waterloo, Waterloo, Canada. He also co-directs the Global Change Initiative – Affordable Energy for Humanity (AE4H), comprising 150+ leading STEM experts, social scientists, and practitioners from 50+ institutions in 30 countries committed to eradicating global energy poverty.

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