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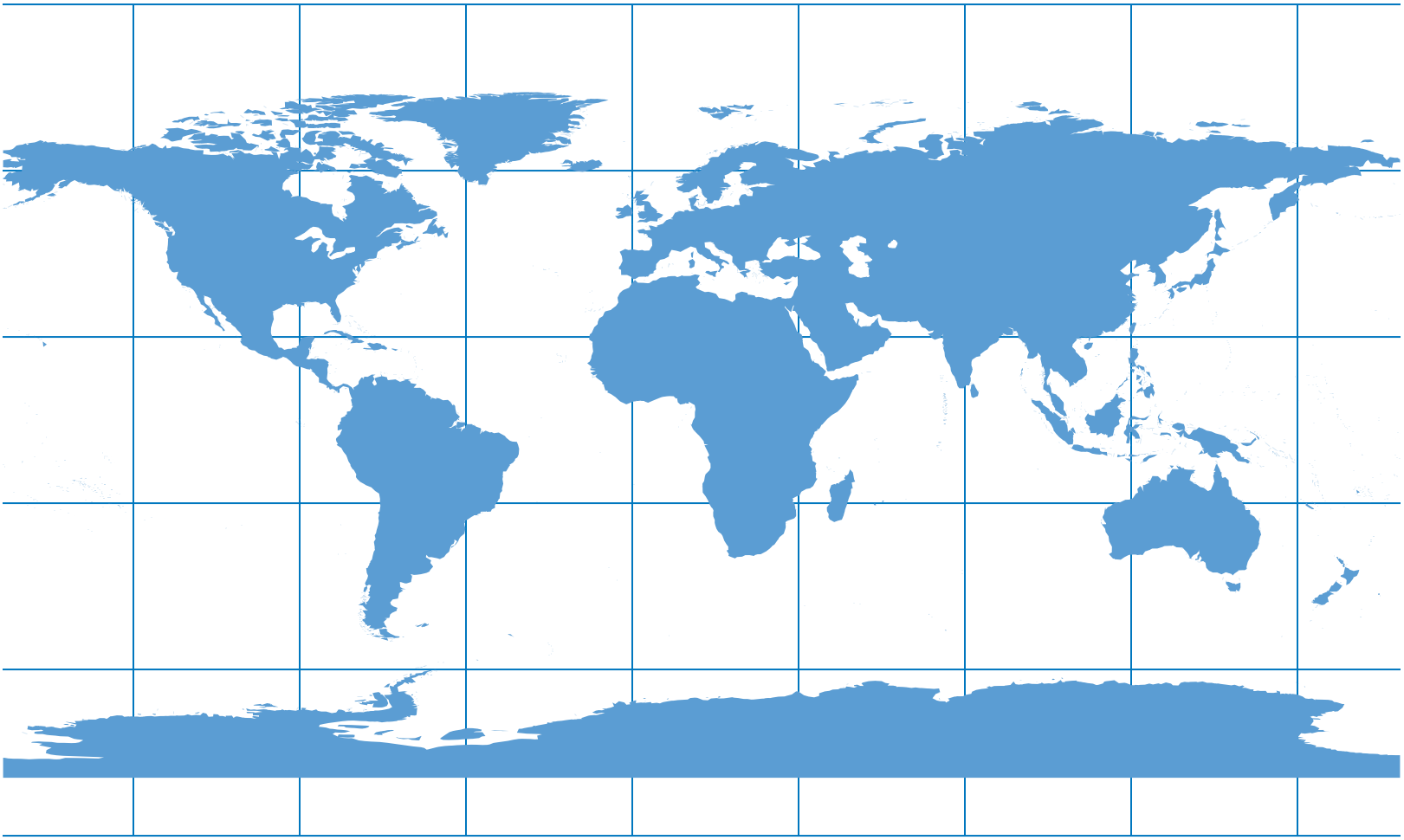
# Frontier technologies for sustainable development



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# Executive summary

## Frontier technologies for a sustainable future

Frontier technologies herald great hopes for humanity. They can help eradicate hunger and epidemics, increase life expectancy, reduce carbon emissions, automate manual and repetitive tasks, create decent jobs, improve quality of life and facilitate increasingly complex decision-making processes. Frontier technologies can indeed make sustainable development a reality, improving people's lives, promoting prosperity and protecting the planet. However, the rapid pace of technological change also introduces significant policy challenges, creating winners and losers in societies and presenting new ethical and moral dilemmas. Notwithstanding these challenges, societies—with the appropriate policies, institutions and international cooperation—can harness frontier technologies to achieve sustainable development, while mitigating their adverse economic and social consequences.

Frontier technologies, which encompass an array of new materials, products, applications, processes and business models, are interdependent, interconnected and mutually reinforcing. Advances in one technology foster progress in others. For example, the invention of new materials is transforming energy production and storage, additive manufacturing and 3D printing; artificial intelligence (AI) is increasingly enabling automation, online search engines and social media platforms; and rapid increases in computing power are enabling breakthroughs in genetics, nanotechnology, blockchains and cryptocurrencies. The present *Survey* focuses only on a selected set of new technologies that are deemed most pertinent and promising for sustainable development.

### Frontier technologies addressing the challenges for people, prosperity and the planet

People and their well-being are often the central focus of many scientific and technological endeavours. Attesting to this, frontier technologies are generating breakthroughs in genetics, nanomedicine, personalized medication, 3D imaging diagnostics and new methods of organ development and transplantation. While those breakthroughs promise to extend longevity and transform human well-being significantly, advances in many health and genetic technologies present ethical conundrums, including the possibility of off-target genetic modifications affecting long-term health and safety considerations. Ethical standards, reflecting fundamental human values adopted and enforced globally, will be instrumental in guiding further advances in these technologies.

Concern for the state of the planet is also driving many innovations. Technological breakthroughs in carbon capture and sequestration have the potential to drastically reduce net emissions and mitigate climate change. The new materials used in photovoltaic cells have great potential for energy efficiency and renewable energy technology. Biodegradable plastic offers a means for reducing plastics pollution, which has become the second most important threat to the environment, after climate change. There are, however, no guarantees that these technological advances will protect the planet on their

own. Policies and institutions will remain paramount in ensuring that these technologies are widely diffused and adopted.

The quest for prosperity is often a key driver of innovation. Humans created machines to perform tasks and improve productivity, and higher productivity in turn delivered new levels of prosperity. Frontier technologies, however, are transforming the relationship between humans and machines. Machines that are now capable of building new machines and solving complex problems, which until recently could be solved only by humans, have the potential to replace humans. Smart robots, equipped with AI, promise to raise productivity to a much higher level and enable production of many new products and services. On the other hand, robots capable of performing "mental labour" are likely to take over many tasks and occupations, potentially leading to higher levels of unemployment. The creators and owners of these robots, however, will clearly become more prosperous—at the expense of the many millions who could lose out in the process. The prosperity of nations may also be at stake, as the robotization of jobs may foreclose manufacturing and industrialization opportunities for many developing countries. Policies must therefore play a critical role in ensuring that frontier technologies leave no one behind and create prosperity for all people and all nations.

## Managing the policy challenges of frontier technologies

Frontier technologies present policy challenges. The complex issues confronted by policy-makers in their efforts to maximize the potential of a new technology are well represented in the case of electric vehicles (EVs), which are already in use in many countries. With near-zero emissions, EVs have a great potential to help realize Sustainable Development Goal (SDG) 13, which is to reduce carbon emissions and combat climate change. The net emission impact of electric vehicles depends, however, on the kind of electricity that they use to recharge. Indeed, while EVs can reduce urban pollution and improve air quality, the net mitigation effect will be limited if their batteries are charged with electricity generated by fossil fuel. Realizing the full potential benefit of one frontier technology thus depends on commensurate advances in other related technologies, which, in the case of EVs, happen to be renewable energy technologies (SDG 7 aims to substantially increase the global share of renewable energy).

### The future of work and inequality

Advances in automation, machine learning, and AI pose similar policy challenges. As these advances increase productivity, they are also transforming labour markets. Routine and repetitive tasks are increasingly being automated, which changes the types of demand for skills. Technology is already being held responsible for many job losses in developed economies. With automation replacing physical labour and AI taking over many analytical functions, achieving one of the targets under SDG 8 (Promote full and productive employment and decent work for all) will become increasingly difficult.

Automation is also contributing to an increase in the share of capital income, while decreasing the share of income flowing to labour, thus leading to a rise in income and wealth inequality. Unless policies are in place to redistribute some of the gains from automation, the process of skills polarization will exacerbate income inequality further

and make the realization of SDG 10 (Reduce inequality within and among countries) even more daunting. Automation could also lead to re-shoring of production from developing countries back to advanced economies, potentially reducing the export earnings and gross domestic product (GDP) of many developing economies and worsening income inequality among countries.

Online technology platforms—which enable individuals or families to use their car or a spare room in their apartment as income-earning capital assets—are promoting new models of the "sharing economy" and creating new opportunities and prosperity. Similar platforms are generating new approaches to work, such as working remotely and working at multiple jobs. Social media platforms are transforming social interactions and creating new business opportunities. Blockchain technology, for example, is making it easier to verify transactions, creating decentralized financial systems and potentially increasing access to financial services. These technologies are bridging many divides—and creating new ones: While holding out great potential for achieving SDGs 3 (Ensure healthy lives and promote well-being for all at all ages) and 4 (Ensure inclusive and equitable quality education), as well as 5 (Achieve gender equality and empower all women and girls), they are also blurring distinctions between employers and employees and consequently raising concerns regarding social protection. National policies and international cooperation will therefore remain key for extracting the full development potential of these technologies.

### Balancing efficiency gains and equity and ethical concerns

It is also the case that social media platforms are increasingly used to produce targeted advertisements, manipulate human emotion, and spread misinformation and even hatred. While AI-based decision-making systems can improve the efficiency of, and access to, public services, they also run the risk of reinforcing existing biases and forms of exclusion. There is thus a clear need for greater transparency and accountability for AI-based decisions. The mass volume of data generated in online platforms provides increasingly important inputs into the process of improving machine learning and artificial intelligence; data are also a critical determinant of the market power of large technology firms. Yet, responses to the questions who should own data and what their true value should be remain contentious. Online data are also increasingly susceptible to hacking and cyberattacks, raising concerns for data security and privacy. Although various policy and regulatory measures are being considered at national or regional levels, an international consensus on data ownership, security and privacy is clearly needed to address ethical concerns and mitigate potential risks, while ensuring that online platforms continue to deliver economic and social benefits.

## Closing the technological gap to bridge the development divide

While developed countries—that is, countries at the technology frontier—grapple with the challenges and seize upon the opportunities associated with frontier technologies, many developing countries are yet to fully reap the benefits of existing technologies. A great technological gap persists, largely explaining the "development divide" between developed and developing countries. More than 1 billion people in the developing countries still do not have access to electricity and an additional 2.5 billion are "under-electrified", experiencing weak connections and frequent power outages. The millions who still depend on human

or animal muscle power for cultivation and other forms of production remain shackled to technologies from the pre-industrial era. They also lack access to modern education and health systems, which are crucial for accumulation of a threshold level of human capital needed for the adoption of many frontier technologies. Creating enabling conditions and bridging the technology divide will remain a key development strategy for many developing countries.

### Leapfrogging to frontier technologies

Frontier technologies also present developing countries with leapfrogging opportunities to achieve the SDGs. The "advantage" of backwardness is that it can enable these countries to avoid or bypass existing less efficient technologies. For example, millions of people in developing countries leapfrogged to mobile phones, without having ever owned or used landline telephones. People in many developing countries, with no electricity until now, are adopting solar electricity, bypassing fossil fuels and leaping directly to the stage of renewables (and contributing to the realization of SDG 7). In fact, many developing countries now derive higher shares of their electricity from renewables compared with many developed countries. It is possible, with appropriate policy measures and strategies, to encourage these developments and accelerate the general process of technological catch-up for many developing countries.

Notwithstanding these potentials, many developing countries—particularly countries in special situations, such as least developed countries (LDCs), landlocked developing countries (LLDCs) and small island developing States (SIDS)—face formidable barriers to leapfrogging to frontier technologies. It is almost impossible for people to secure access to digital technologies and online economic opportunities without electricity and broadband Internet connections. However, enabling physical infrastructures constitutes a necessary, but clearly not a sufficient, condition. Without a minimum level of education, it is not possible to utilize digital technologies to buy or sell goods online, for example, or offer car services or rent out an apartment, even if the requisite electricity and Internet connection are in place. It is therefore not fortuitous that the few instances of leapfrogging—through, e.g., adoption of solar energy and mobile phones—became possible for technologies that do not require high levels of human capital. This demonstrates that leapfrogging to frontier technologies also requires advances related to achieving other SDGs such as "to ensure healthy lives" (SDG 3), "to ensure inclusive and equitable quality of education" (SDG 4), and "to build resilient infrastructure" (SDG 9). In order to bridge the technology and development divides, national development strategies will therefore need to target both basic infrastructure development and human capital accumulation

## National innovation systems fostering technological progress

That national innovation systems (NIS)—formal or informal—drive innovation, diffusion and adoption of new technologies is true both for countries at the technology frontier and for the technologically following developing countries. Innovation, however, is not always synonymous with a technological breakthrough, i.e., a one-of-a-kind, grand-scale invention. It can also entail small-scale, incremental—or even imperceptible—

improvements and improvisations of processes and products. National innovation systems in technologically advanced countries are generally more focused on innovation, while the NIS of technologically following countries for the most part prioritize adaptation. While infrastructure and human capital are necessary preconditions for technological catch-up, their quality and efficacy are largely determined by the NIS, which comprises interconnected institutions that create, store and transfer new technologies. More broadly, the NIS constitutes a network of universities, research institutions, and the research and development (R&D) departments of industrial firms and utilities. An NIS can drive both the creation of new methods for production of pre-existing products and services (process innovation) and the creation of new products and services (product innovation).

### Aligning the national innovation system with development priorities and contexts

There is no single model of a national innovation system. Its size, scope and effectiveness are determined by country-specific priorities and contexts. The relative size and influence of various actors—public and private—are an important determinant of a national innovation system. Systems can also differ across countries depending on the relative importance they attach to basic or applied research. An NIS can prioritize indigenous research, instead of importing, or relying on, foreign technologies, or vice versa. In general, the private sector plays a more important role in the NIS of advanced countries, while the public sector usually plays a more dominant role in developing countries, simply because the private sector in those countries often does not have enough R&D capability. Similarly, the NIS in a technologically following country is likely to be more focused on application, while that of advanced countries can focus on both basic science and application. Notwithstanding these differences, it is critically important that the objectives and operations of the NIS be aligned with national development priorities.

Developing an effective NIS that fosters innovation, diffusion and adoption is particularly important for developing countries, given that the current, uneven pace of technological breakthroughs may further widen the technological divide that persists between developed and developing countries. An NIS will need to address—or may even need to overcome—continued divergences in the ability of firms and countries to innovate and adopt existing technologies; growing market power concentration, especially of firms dominating the digital sphere; and increasingly stringent and restrictive intellectual property rights (IPR) regimes. This will require revamped and scaled-up international cooperation, reflecting shared and differentiated responsibilities among all countries for managing the impacts of frontier technologies.

## International cooperation for managing frontier technologies

International cooperation will remain key to bridging this persistent, and possibly growing, technology divide among countries and there is a clear need to broaden and strengthen technology transfer and diffusion mechanisms. While trade and foreign direct investment (FDI) have generally been the most important channels of technology transfer and diffusion, intellectual property rights as embedded in various trade and investment agreements are

exerting an increasingly restrictive influence in this regard. While international efforts are scaled up to ease IPR restrictions, developing countries can make use of the growing number of pooled-knowledge networks—facilitated by the Internet—to accelerate the pace of their technological progress and so catch up.

The speed of diffusion and proliferation of many frontier technologies; the way they cross jurisdictional, regulatory and disciplinary borders; and how they embed, shape and exploit human values and bias render traditional and national-level regulations inadequate, if not irrelevant. The new reality ushered in by many frontier technologies calls for stronger and more effective international cooperation. As stated by the Secretary-General (United Nations, 2017a), it is crucial to avoid the naïve idea that "traditional forms of regulation" will work to address the challenges of the future. New regulatory mechanisms for managing frontier technologies must bring together all stakeholders: not only Governments, companies and scientists, but also the civil society and academia. These frameworks must strike a balance between fostering innovation and efficiency on the one hand, and fairness, equity and ethics on the other. Such a balance will be critical for ensuring that frontier technologies deliver sustainable development and leave no one behind.

## Strengthening competition policy and international tax cooperation

In particular, international cooperation will be needed to address the growing and excessive concentration of market power among a few large technology firms, as a pathway towards both addressing efficiency-, equity- and ethics-related issues and bridging the technology divide among countries. The "winner-takes-most" phenomenon has allowed a small number of firms to dominate their respective industries at the global level, thereby limiting the scope of regulations at the national level. Moreover, excessive concentration of market power can hinder further innovation and diffusion of frontier technologies within and across countries. There is also a strong need to strengthen international tax cooperation so as to ensure that multinationals—particularly large technology firms operating and adding value globally—are taxed effectively. The current international tax framework—designed with the traditional bricks-and-mortar economy in mind—is often ineffective when it comes to taxing the intangible value added and digital transactions associated with many frontier technologies.

International cooperation to ensure an even playing field at the global level is imperative. For example, stringent regulations in one country will create opportunities for regulatory arbitrage if other countries do not enforce similar regulations. Furthermore, a "race to the bottom" can occur if countries use lax regulation as a strategy for attracting new businesses, getting ahead of the curve and exploiting the first-mover advantage. Absent robust international cooperation, national-level efforts to increase competition and to prevent tax avoidance and tax evasion will become increasingly ineffective. International tax cooperation will be particularly important with respect to taxing profits, which are mobile across borders and often difficult to measure. There is also a clear need for forging consensus at national levels to ensure that the new and additional tax revenues generated are utilized to minimize the short-term adverse impacts of frontier technologies on wages and income inequalities.

## The role of the United Nations in forging global collective actions

The United Nations, given its legitimacy and global mandates, is in a unique position to forge a global consensus, ensuring that international cooperation for managing frontier technologies is rooted in and guided by universal values and obligations—as defined in the Charter of the United Nations, the Universal Declaration of Human Rights,[1] and the 2030 Agenda for Sustainable Development.[2] The United Nations remains a trusted venue where Governments, industry, academia, civil society and others can come together to make collective choices regarding new technologies—openly, transparently and based on shared values. Effective engagement on new technologies will clearly require close partnership with a range of government, industry, academic and civil society partners. The United Nations will also need to remain open to new ideas and new voices and engage credibly and objectively with all partners.

The United Nations can leverage its convening power to bring Member States and all relevant stakeholders together to adopt a global consensus on legal and ethical standards for guiding research and development of frontier technologies. The need for global standards is particularly acute for managing progress in AI in such a way as to increase accountability and transparency of AI-based decisions. Global ethical standards are also needed to guide current and future research on genetic technologies, especially gene editing, as they may fundamentally transform the human species.

The United Nations can play a vital role in supporting the identification and designation of certain frontier technologies that can be critical for achieving the Sustainable Development Goals. Renewable energy technologies that promote environmental sustainability, vaccines that save lives, and biotechnologies that boost food production and eliminate hunger are all critically important for achieving sustainable development and securing our common future. Building a sustainable future will require the United Nations to facilitate development, diffusion and adoption of these technologies based on shared responsibilities of all actors.

## Outline of the *Survey*

Following this broad vision, Chapter I of the *Survey* presents a case for harnessing frontier technologies to achieve the shared vision of sustainable development, while minimizing their adverse and disruptive effects. The chapter highlights a few of the remaining challenges for the planet, people and prosperity as humanity strives to achieve sustainable development. It then reviews the relevance and challenges of a select set of frontier technologies in the context of the SDGs. Chapter II discusses the promises and challenges of a few frontier technologies in developed country contexts. Chapter III highlights the development divide and the difficulties—particularly the technological divide—that many low-income and vulnerable countries face in adopting frontier technologies and leapfrogging development. Chapter IV explains the role of national innovation systems and how they can bridge the persistent technological divides between developed and developing economies. Chapter V concludes the *Survey*, discussing the imperatives of international cooperation and coordination, and the special role of the United Nations, for managing frontier technologies to realize the 2030 Agenda for Sustainable Development.

1 General Assembly resolution 217 A (III).

2 General Assembly resolution 70/1.