TFM findings 2021

Prepared by the UN Interagency Task Team on Science, Technology and Innovation for the SDGs, Work Stream 10 on "Analytical work on emerging science, frontier technologies and the SDGs"

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Summary

The present document presents the updated 2021 TFM findings on the impact of rapid technology change on the achievement of the SDGs. The TFM findings represent a collaborative, multi-stakeholder achievement. Experts from within the UN and outside have contributed, including through virtual meetings and over 40 dedicated science-policy briefs.

A special thank you for their substantial contributions goes to the TFM 10-Member-Group, colleagues from DESA, UNCTAD, ITU, ILO, ESCWA, UNEP, UNIDO, UNESCO, ESCAP, UNU, WFP, OOSA, UNDP, WIPO, and World Bank, as well as the many external experts.

We must ask: how are things different in the face of our experience with COVID-19? What does it mean for the way forward? The 2021 TFM findings provide partial answers.

New elements of TFM findings

The 2019 TFM findings remain valid, but new elements are needed.

COVID-19 has greatly amplified the importance of STI for our well-being, even for our survival. But it has also exposed weak interfaces with policy and society, and ineffective institutions, often victims of underfunding.

COVID-19 has accelerated digitalisation, along with its now well-recognized impacts, both positive and negative. Vitally, 3 billion unconnected are still excluded. This has worsened existing technology divides.

The crisis has accelerated innovation in medicines, vaccines, biotechnology, digital technologies and artificial intelligence. Scientific discovery and collaborations have sped up, new ways of delivering services have proliferated.

Our pre-pandemic innovation system had operated well below its real potential, but we can supercharge it in times of crisis. However, we should not forget that mission-oriented innovation of this type has benefitted from international R&D cooperation and billions in public funding for "vaccine platforms", mRNA technology and massive online learning. Therefore, the returns from these must also be broadly available to the public.

The pandemic financial stimulus has been enormous, but not yet focused on longer term measures for a human-centred, green, sustainable, R&D- and technology-focused recovery. The R&D underinvestment is puzzling: surely the crisis has demonstrated its importance.

Public funding for basic research needs to be greatly expanded and sustained even beyond these times as a vital part of our resilience strategy. Consider this: the fundamental biotechnology knowledge that made rapid COVID-19 vaccine development possible was due to years of public funding for basic research.

Frontier technologies have made a real difference in COVID-19 responses. Examples include contact tracing apps; space science; viral spread simulations on supercomputers; PCR testing; mRNA-based vaccines; synthetic nano-scale antibodies; 3D printing of PPE; and big data to support policy effectiveness.

Massive drive for COVID vaccines must be replicated for the 20 neglected tropical diseases which continue to affect one billion people. At the same time, questions of access can no longer be put on the back burner. The task team brought together proponents of open science on the one hand and of strict intellectual property rights on the other. Interestingly, they agreed that there is no fundamental contradiction between the two and that there are constructive ways forward for addressing the great global challenges.

A worldwide, profound techno-economic paradigm transition is under way towards a greener global economy. It creates new windows of opportunity for innovations, productive transformation, and new jobs and employment opportunities. This transition needs to be managed in a process of social dialogue in order to generate a just, fair and inclusive transition process.

Science systems must be transformed. The pandemic revealed deficiencies in the capacity of science systems to respond to new priorities in a timely manner, while limiting the disruption to ongoing research.

The new governance around data makes it complex to re-balance human dignity with economic benefits, thereby putting fundamental human rights at risk in the new economy. Fair data, transparent algorithms, and trustworthy architecture are essential.

Digitalisation leads to entirely new products and services with new characteristics that require specific regulatory and policy solutions. For example, human digital twins entail a range of ethical dilemmas. Central bank digital currencies must be regulated to be inclusive, secure, private, accessible and interoperable. Digital labour platforms need to be covered by labour regulations to provide decent work.

"Deep neural networks" now surpass human cognitive capabilities in narrow, specific tasks, such as facial recognition, some kinds of medical diagnosis, and others. Narrow AI has become ubiquitous in many countries – unbeknownst to many. However, billions remain excluded from its benefits. Performance and applications grow at exponential rates, with important implications for the SDGs. For example, AI energy use is expected to increasingly compete with other uses.

There are many environmentally compatible frontier technologies which could be deployed across the world. Examples include distributed recycling combined with additive manufacturing, highly energy-efficient AI hardware designs, low data AI, engineering solutions imitating nature, marine robotics, and saltwater greenhouses. There is also a large untapped potential for highly efficient digital consumer innovations in mobility, food, buildings, and energy services.

Syntheses of science-policy assessments are important to enable informed and integrated decision-making in relevant time. However, major knowledge and assessment gaps remain with regard to digitalisation and other related frontier technology clusters. Independent and in-depth assessments are needed.

Previous findings remain valid

Previous findings remain valid and included, inter alia, the following. In fact, the COVID-19 crisis has further amplified several of them which calls for even more urgent action.

The potential benefits of new and rapidly changing technology clusters are so great for the SDGs and beyond that we cannot afford not to make use of them. Technology change creates winners and losers, involving risks, and potentially exacerbating gaps and inequalities.

Rapidly declining costs of new technologies can broaden access to the benefits of technology and enable much more rapid development, but they also present extraordinary policy challenges that call for an extraordinary level of international cooperation. Many countries may need to find new development pathways that incorporate these technologies and to rethink employment and income distribution issues.

The overall employment effects will depend on the specific circumstances within sectors and various local contexts. Computers and robots could replace as many as half of all human jobs in the coming decades - essentially precluding traditional routes to achieve economic development in some countries, but they could also create many new jobs. It is unclear how jobs losses and job creation will compare and how they will be distributed, however, we need to be prepared for different scenarios to unfold.

Governments will need to re-think and re-organize how they match the supply of skills to the rapidly evolving job market needs in formal and informal education systems. Some TFM experts call for testing proposals for technological unemployment insurance, guaranteed income policies, and a range of other compensatory social policies.

New materials, digital, bio-, and nanotechnologies, and AI all hold great promise for water and renewable energy systems. Environmental considerations should be incorporated into the design of these technology systems from the start.

Our knowledge and understanding of new technology trends – especially in developing countries - need to be expanded as the basis for well-founded actions and policies. TFM experts proposed building partnerships and interfaces with universities, labs, innovation incubators, and private sector entities that are at the forefront of this technological change, potentially in the form of a discovery lab or a network of interfaces between the policy makers and technologists at the frontier, facilitating the exchange of real-time information, engagement, and policy insights.

Calls for a more responsible and ethical deployment of new technologies have to be balanced against concerns that excessive restraints on innovations may deprive humanity of many benefits.

Fostering policy coherence and multi-stakeholder dialogue is more important than ever - coherence across policies for macro-economy, science and technology, industrial development, human development and sustainability; and multi-stakeholder dialogue to present different perspectives, arrive at shared understanding and establish trust.

Looking ahead

Rapid scientific and technological change is among us, and it is not going away. The COVID-19 shock has forced a re-examination of virtually everything we do.

The current TFM findings stand to be refined further through discussions at this Forum and beyond. They also serve to indicate central areas of work, where the TFM stands ready to add value and advance understanding.

When we work together – across national borders, across groups, disciplines and stakeholder groups - we as humanity can harness science and technology to the benefits for all of us, now and into the future. We hope that the findings of the TFM presented here will support this endeavor.

TFM findings

This chapter presents the so-called "TFM findings on the impacts of rapid technology change on the SDGs" which have been traditionally presented by the UN Chief Economist in the annual Multi-stakeholder Forum on Science, Technology and Innovation for the SDGs (STI Forum). The findings are based on a wide range of inputs, including but not limited to the present report. In other words, this chapter is not only a summary of the present report but draws on other sources as well.

A. Context and objective

The fast pace of technological change in recent years in robotics, artificial intelligence, biotechnology, nanotechnology and related areas such as "big data" are having broad impacts on economy, society and environment. At the heart of these trends are information and communication technologies, and an increasing number of key scientific and technological capabilities. While such disruptive technologies can be vital for breakthroughs in achieving the SDGs, they can also have un-anticipated consequences, exacerbate inequalities, and constrain economic catch-up development. Calls for a more responsible and ethical technology deployment have to contend against those who fear constraining innovations may deprive people of many benefits. In this context, multi-stakeholder engagement is essential, because many technology advances are initiated in the private sector and academia.

The UN Technology Facilitation Mechanism (TFM) was created by the Addis Ababa Action Agenda and launched by the 2030 Agenda on Sustainable Development in September 2015. The creation of the TFM was of historic significance, as it brought back substantive STI discussions to the UN HQ, after decades of political gridlock.

One of the components of the TFM is the Multi-Stakeholder Forum on Science, Technology and Innovation for the SDGs ("STI Forum"). The STI Forum formally reports to the High-level Political Forum on Sustainable Development (HLPF) in support of its review of SDG progress and its explicit function to "strengthen the science-policy interface".

The STI Forum has become the premier UN multi-stakeholder space for discussions on STI for the SDGs, including cross-SDG issues such as emerging technologies and their sustainable development impacts. The STI Forum proposed a list of initial recommendations, including on STI roadmaps, and on the impacts on societies caused by the disruptive effects of new technologies, such as nanotechnology, automation, robotics, artificial intelligence, gene editing, big data, and 3D printing. Emerging technologies and frontier issues have been the subject of STI Forum sessions since the very first Forum in 2016. The STI Forum complements the intergovernmental deliberations in the UN Commission on Science and Technology for Development and various sectoral, thematic and regional forums in the UN system.

Another component of the TFM is the Inter-agency Task Team on Science, Technology and Innovation for the SDGs ("IATT"). It brings together 45 UN system entities and more than one hundred staff. They work closely with the "10-Member Group" representing science, civil society, and private sector, including in order to assess the impacts of rapid technological change on the SDGs. UN expert group meetings were held in Mexico City (2016 and 2018), Paris (2017), Incheon (2017), Vienna (2020), and online in Aril 2021. These meetings have mobilized many scientists and experts, and the subject has featured in successive STI forums. The discussions on the impacts of digitalization, artificial intelligence, biotechnology, nanotechnology, and other technologies are expected to continue.

In the IATT, this work has led to a dedicated work stream on analytical work in which staff have cooperated for several years. It built on related work undertaken by IATT members with various partners on new and advanced technologies since the Rio+20 Conference of 2012.

The topic became the primary focus of General Assembly resolutions 72/242 and 73/17 on the impacts of rapid technology change which requested presentations of TFM findings at the STI Forums. Initial TFM findings were presented by the UN Chief Economist at the STI Forum in 2018 and an update in 2019. Similarly, this year, an update of these TFM findings will be presented at the STI Forum during a session on "Emerging science and technology trends, divides and the SDGs" on 5 May 2021.[1] The findings are documented in this chapter.

B. Previous TFM findings

The last time that "TFM findings on the impacts of rapid technology change on the SDGs" were presented was in the STI Forum in 2019, since the Forum in 2020 was postponed to this year.

The Task Team's findings in 2019 represented a collaborative and multi-stakeholder effort with more than 100 expert contributors. It built on evidence from eight meetings and sessions under the TFM umbrella; ten recent UN system reports; written inputs from IATT and the 10-Member Group, and 50 science-policy briefs volunteered by expert contributors. In particular, experts of DESA, UNCTAD, UNU, ECLAC, ESCAP, ESCWA, ITU, ILO, WIPO, World Bank, as well as the International Council on Science and the Major Group on Children and Youth made substantial contributions.

In 2019, views in the highly diverse TFM community continued to differ, but consensus was also growing on many points. The IATT approach then as now was to simply document the debate, the evidence and the recommendations put forward.

The following table summarizes these 2019 TFM findings in nine focus areas. The scope and scale of the impacts of rapid technological change - both positive and negative – had accelerated across the range of economic, social, and environmental dimensions. At the time, the task team concluded that the TFM findings had "stood the test of time" and had not changed substantially from 2018, even though some of the impacts had increased in intensity, indicating a need for policy action.

The findings highlighted the great potential of new technologies to further sustainable development. They highlighted the need for the UN to promote action to address global technology risks and gaps. They called for "extraordinary levels of international cooperation" against the backdrop of ever cheaper automation and AI, in order to enable feasible development pathways for all countries. New ideas are needed to manage the highly uncertain employment impacts and concentration of income and wealth. Some TFM experts specifically called for testing proposals for technological unemployment insurance, guaranteed income policies, and a range of other compensatory social policies. Environmental considerations should be incorporated from the very start into the design of the new digital and AI technology systems, in order to avoid lock-in to an unsustainable, high-energy and high-materials demand pathway. The science-policy interface needs strengthening and knowledge base related to the impacts if technologies especially in developing countries requires international support through systematic partnerships with universities, labs, innovation incubators, and private sector entities that are at the forefront of this technological change, potentially in the form of a discovery lab, facilitating the exchange of real-time information, engagement, and policy insights. Ethical and normative considerations should guide our actions in practical ways. And finally, fostering policy coherence and multi-stakeholder dialogue remains as important than ever, in order to present different perspectives, arrive at shared understanding and establish trust.

[1] Summary of the "TFM findings" of 2019: https://sustainabledevelopment.un.org/content/documents/22742IATT_policy_brief_new_and_emerging_techs.pdf

2019 TFM findings on the impact of rapid technology change on the SDGs (Status: May 2019)	
Great potential towards achieving the SDGs	The potential benefits of new and rapidly changing technology clusters are so great for the SDGs and beyond that we cannot afford not to make wise use of them.
Technology risks and gaps	Technology change has never been neutral, creating winners and losers, involving risks, and potentially exacerbating gaps and inequalities. The UN has an important role in identifying, raising awareness and promoting action on these issues.
Development impacts of cheap automation and AI	Rapidly declining costs of new technologies can broaden access to the benefits of technology and enable much more rapid development, but they also present extraordinary policy challenges that call for an extraordinary level of international cooperation. Many countries may need to find new development pathways that incorporate these technologies and to rethink employment and income distribution issues.
Employment impacts	The overall employment effects will depend on the specific circumstances within sectors and various local contexts. Computers and robots could replace as many as half of all human jobs in the coming decades - essentially precluding traditional routes to achieve economic development in some countries, but they could also create many new jobs. It is unclear how jobs losses and job creation will compare and how they will be distributed, however, we need to be prepared for different scenarios to unfold.
Preparing for the impacts	Governments will need to re-think and re-organize how they match the supply of skills to the rapidly evolving job market needs in formal and informal education systems. Some TFM experts call for testing proposals for technological unemployment insurance, guaranteed income policies, and a range of other compensatory social policies.
Natural environment	New materials, digital, bio-, and nanotechnologies, and AI all hold great promise for a range of high-efficiency water and renewable energy systems that could be deployed in all countries and catalyse the global move towards sustainability. However, despite efficiency increases, AI and all the other emerging technologies clusters will require ever-increasing electricity with its associated pollution and wastes (e.g., e-waste, nano-waste, and chemical wastes), which calls for incorporating environmental considerations into the design of these technology systems from the start.
Strengthening the science-policy interface	Our knowledge and understanding of new technology trends – especially in developing countries - need to be expanded as the basis for well-founded actions and policies. TFM experts proposed building partnerships and interfaces with universities, labs, innovation incubators, and private sector entities that are at the forefront of this technological change, potentially in the form of a discovery lab or a network of interfaces between the policy makers and technologists at the frontier, facilitating the exchange of real-time information, engagement, and policy insights.
Norms and ethics	Calls for a more responsible and ethical deployment of new technologies have to be balanced against concerns that excessive restraints on innovations may deprive humanity of many benefits. Ethical and normative considerations that should guide our thinking on these issues have to spring from our shared vision - the values contained in the UN Charter, the Universal Declaration of Human Rights, the Rio+20 outcome "The Future We Want", and most recently the 2030 Agenda on Sustainable Development.
Multi-sectoral and multi-stakeholder engagement	Fostering policy coherence and multi-stakeholder dialogue is more important than ever - coherence across policies for macro-economy, science and technology, industrial development, human development and sustainability; and multi-stakeholder dialogue to present different perspectives, arrive at shared understanding and establish trust.

Sources: IATT WS10 on analytical work on emerging science, frontier technologies and the SDGs.

The 2019 TFM findings also reported on latest activities by IATT partners on new and emerging technologies. The Centre for Artificial Intelligence and Robotics became operational in the Netherlands under the umbrella of the UNICRI. OICT launched a series of UN Technology and Innovation Labs, starting with project offices in Finland and Egypt. ITU's AI for Good Global Summit featured practical AI solutions for the SDGs. The UN Secretary General created a High-level Panel on Digital Cooperation and launched a Strategy on New Technologies. UNDP joined the Partnership on Artificial Intelligence - a consortium of companies, academics and NGOs. Current IATT efforts on the development of the TFM online platform focus on an AI design. The UNU Centre for Policy Research created an AI and Global

Governance Platform as a space for public policy dialogue. DESA published the World Economic and Social Survey 2018 on the theme of Frontier technologies for sustainable development. The 36th session of the CEB HLCP focused primarily on frontier technologies, with discussions on capacity development for AI and the future of work. The technology chapter of the Financing for Development Report 2019 was again dedicated to new and emerging technologies. UNCTAD launched its Technology and Innovation report 2018 on Harnessing Frontier Technologies for Sustainable Development. CSTD 2018 and 2019 addressed the issue – this year supported by a Secretary General's report on The Impact of rapid technological change on sustainable development. Recently, a compilation of 50 science-policy briefs on frontier technology issues was made available on the TFM website. These examples were merely a glimpse of the many new in the UN system activities on new and emerging technologies at the time. They were testament to the high expectations attached to these technologies.

C. New elements in 2021 TFM findings and looking ahead

Two years later and more than one year into the COVID-19 pandemic, the interagency task team, of course, explored to which extent the previous TFM findings remained relevant and whether new elements would need to be added.

To answer these questions required the team to also consider lessons-learned from COVID-19. What difference have emerging science and frontier technologies made in our responses? Where have they failed and where have they succeeded? And what does it all mean for the global technology divides?

Process

To answer these questions, the task team reached out for inputs to all 45 UN entities that are IATT members, the UN Secretary General's 10-Member-Group and the STI communities they represent, to organized science and engineering communities, as well as to interested experts in academia, civil society and the private sector. A call for inputs resulted in hundreds of inputs, including many science-policy briefs submitted by experts, more than 40 of which passed the peer-review and are included in this report. In addition, the task team organized a UN expert group meeting on 8 April 2021 to support identification of new elements for the TFM findings. The meeting addressed in particular topics for which a wide range of perspectives continue to exist in the task team, including on emerging science (what have science-policy assessments told us in the past year and what should be their role in the future?); biotechnology, vaccines, and health technologies (what is needed for closing global divides post-COVID?); the future of artificial intelligence and technology divides (what should be done?); and open science and intellectual property issues (how to align processes for frontier technologies based on what we learned during the COVID pandemic?).

The following findings represent a collaborative, multi-stakeholder achievement. Experts from within the UN and outside have contributed. Special credit goes to the current and former 10-Member Groups and colleagues from DESA, UNCTAD, ITU, ILO, ESCWA, UNEP, UNIDO, UNESCO, ESCAP, UNU, WFP, OOSA, UNDP, WIPO, ICGEB, and World Bank for their substantial contributions.

Findings

2019 TFM findings remain valid, but new elements need to be added

The COVID-19 pandemic has "hammered" home the continued relevance and importance of the 2019 TFM findings and the urgency to act upon them. They remain fully valid. At the same time, the deficiencies of our current global science and technology system have been exposed. Important new elements need to be added to the TFM findings – elements that have always been important, but the pandemic has highlighted the urgency for action and the costs of inaction, mostly in rather stark terms. Barely a year after WHO declared the pandemic, over three million have perished and around one billion have been infected, many of which with potentially long-term health effects.

COVID-19 has greatly amplified the importance of STI but weak institutions have been exposed

The COVID-19 pandemic has greatly amplified the importance of science, technology and innovation (STI) for our well-being, even for our survival. New scientific findings and technologies are the solution to the crisis, and in the areas of medicines, vaccines and digital technologies they have delivered for humanity in a record time. Yet, the crisis has exposed weaknesses in institutions – political, administrative and scientific institutions, some of which have long suffered from underfunding and deficient governance. Many of the lessons from the pandemic relate to science, including basic recommendations to strengthen health care, invest in science and education, build trust in science, and improve the science-policy interface.

COVID-19 has accelerated digitalization but also increased the cost to the 3 billion unconnected

COVID-19 has greatly accelerated digitalisation among those who were already online at the beginning of 2020, making the Internet pervasive. As of Jan. 2021, globally an estimated 4.8 of 7.8 billion people were Internet users.[2] When businesses, schools and governments in many parts of the world switched to telecommuting and video calls in spring 2020, Internet traffic increased by around 40 per cent worldwide in the matter of one month. Reportedly, this massive move in response to the enduring crisis has greatly accelerated innovation in digital technologies and applications.

On the flipside, 3 billion people remain offline and deprived from online education, employment or digital innovations. The pandemic greatly exacerbated existing technological and social divides – an unresolved issue that needs urgent addressing. Billions of people remain completely excluded.

While the pandemic instantly expanded the user base and market for many new services, it is also important to note that some underlying, pervasive technology trends have continued with surprising regularity, despite the COVID shock. For example, the super-exponential growth in performance and energy use by large-scale providers, such as Google, Facebook, and Amazon Web Services since 2017 has continued without delay.

Replicating innovation acceleration due to COVID-19 in other areas

In some ways, our global innovation system in "normal" times has operated well below its potential. But the good news is that the ongoing COVID-19 crisis has shown that we can supercharge it in times of crisis. The enduring pandemic has accelerated innovation in medicines, vaccines, digital technologies and artificial intelligence, as many social and economic activities were moved online, quasi overnight. Leveraging on these experiences holds promise for our greatest collective trials beyond COVID-19 - curbing climate change, resolving inequalities and resetting our unsustainable relationship with nature.

While vaccination campaigns remain in catch-up mode with virus mutations due to high infection case numbers, the quick development of vaccines with high efficacy and their testing in unprecedented record times is testament to the resilience and capability of the global innovation system. A key question is to which extent the innovation system could be equally mobilized to invent, innovate and deploy new technologies to address socio-economic, environmental and other sustainable development challenges. It is important to note that mission-oriented innovation of this type has benefitted from earlier global R&D cooperation and public funding for "vaccine platforms", mRNA technology, massive online learning, etc.

The innovation acceleration that we have witnessed during the present crisis gives us reason for cautious optimism about possible innovation-driven solutions also in other areas of sustainability concern. However, many opportunities have been missed, especially in terms of better global cooperation, global solidarity, and trust in science. In fact, the world broadly remains on a business-as-usual trajectory

Reorienting financial stimulus packages

The world remains in fire-fighting mode. The vast majority of financial stimulus packages in response to the pandemic are not yet focused on longer term measures for a green, sustainable, R&D- and technology-focused recovery, in order to increase resilience to future sustainability crises.

In view of the large size of these packages totalling US$17 trillion worldwide, they may crowd out more sustainable investments and lead to increased lock-in on a business-as-usual pathway. Of a total of US$14.6 trillion[3] in national fiscal measures to address the crisis, $11.1 trillion were directed to immediate rescue efforts (to manage the short-term effects) and $1.9 trillion to longer-term *recovery measures*.[4] The total accounted for about 23% of GDP of advanced economies in the sample and 11% of GDP of emerging market and developing countries. Of the recovery

[2] 2.7 billion of them Facebook users. In a typical day in that month, they sent 265 billion emails, made 794 million tweets, watched 7.5 bill. youtube videos, made 453 million skype video calls and uploaded 89 million videos and much more, producing an incredible 9.4 bill. GB/day of Internet traffic. In the same day more than 4.3 million smart phones and almost one million computers were sold.

[3] $17 trillion with commitments by the European Commission

[4] another US$1.6trillion was recorded as unclear spending.

measures, only 18% or US$341 billion was "green" or environmentally compatible spending. Almost all of this green recovery spending was in only seven countries. So, only 2.3% of stimulus funding (accounting for 0.4% of GDP) was green. Furthermore, most of the green recovery spending has been committed to electric vehicle transfers and subsidies, investments in public transport, cycling and walking infrastructure, followed by subsidies for renewable energy and infrastructure; ecosystem regeneration and public parks, and energy-efficient building retrofits. In comparison stimulus spending on research, development and demonstration for sustainable technologies is negligible. Given the role of science and technology as solution to the pandemic, this is incredible underinvestment in R&D. This fact also aligns with anecdotal evidence even from a Nobel prize winner and TFM contributor who reported how hard it was to raise funding for R&D in biotechnology.

Greatly scale up public investment into basic research

The fundamental biotechnology knowledge which permitted the development of COVID-19 vaccines in record time largely originated in public and non-profit research institutions and spin-offs thereof. It was thus primarily due to public funding for basic research. Yet in the crisis, unprepared pharmaceutical companies received tens of billions of dollars to support applied research, production scale-up and population testing. No commensurate public investment increase was made into basic research. There is an urgent need for acknowledging the decisive role of public funding for basic research and for greatly increase such investment.

Align research priorities with SDGs

Most scientific research is concentrated in a few high-income countries and tends to focus on challenges that are not relevant to SDG challenges in low-income countries. Funders, donors and international organisations should seek to steer research priorities, including by consulting with a wider range of stakeholders and improving the assessment of research's (unequal) impact on societies.

Many successful technology solutions in COVID response

Many effective frontier technology solutions have been documented in COVID-19 responses in developed and developing countries alike. However, their successful deployment requires skills and capacities. Therefore, capacity development and demonstration projects are key. Public maker spaces and citizen labs may be a useful start. Examples of such solutions include: big data to support the assessment of policy effectiveness; contact tracing apps; space science and technology for global health; viral spread simulations on supercomputers to identify optimal behavioural guidelines; polymerase chain reaction (PCR) testing and alternative diagnostic tools; mRNA-based vaccines rapidly responding to virus mutations; synthetic nano-scale antibodies; and 3D printing of face shields and PPE.

Frontiers in vaccines and access to STI solutions

A number of lessons can be drawn from the pandemic. The science and technology of vaccines had already progressed significantly – long before the COVID-19 pandemic, although funding for researchers and innovators has been difficult to come by. Then in the matter of weeks, at some point last year, more than one hundred COVID-19 vaccines based on a range of biotechnologies were under development. As of the end of April, an estimated one billion vaccine shots have been administered world-wide – barely more than one year after the WHO declared the pandemic. Compared to the past, this is an incredible scientific, technological and logistical achievement.

How could the massive drive for vaccines be replicated to address the 20 neglected tropical diseases which continue to affect one billion people? Something akin to "pandemic times" has always been the "normal" state of affairs for the poor of this world. Every year, 1.4 million die from tuberculosis. And 5 million children under the age of 5 die from preventable causes – far more than this year's death toll of COVID-19. The big question is what could be done to provide a commensurate level of support to the science and technology of vaccines and medicines in these other areas.

And how can access be ensured to vaccines and the technologies to develop and manufacture them? The task team brought together proponents of open science on the one hand and of strict intellectual property rights on the other. Interestingly, they agreed that there is no fundamental contradiction between the two and that combinations thereof can be optimised and useful for addressing the great global challenges. The debate uncovered significant room for serving the original common objectives. The shared values of dissemination of information, knowledge, processes, and data for enabling wider dissemination of the benefits of science, and technology for all. Due to their network effects, knowledge assets tend to earn higher value with more users unlike physical wealth counterpart.

Latecomer development in the emerging global green economy

A worldwide, profound techno-economic paradigm transition is under way towards a greener global economy. The transition is driven by deliberate changes in polices, strategies and institutions, which create 'green windows of opportunity' for developing and emerging economies, due to mission-guided technical change and market development. Policy makers need to deliberately bring together, otherwise distinct, policy domains, and co-design solutions. Policies need to be sensitive to the technological specificities of the different green sectors.

Transforming science and engineering systems

The pandemic revealed deficiencies in the capacity of science systems to respond to new priorities in a timely manner, while limiting the disruption to ongoing research. Perennial issues of persistent inequalities in science and limitations of the current system of publication and peer-review were also brought to the fore. Against such background, science systems must be transformed, including through strengthening the directionality of science; changing the practice of science; enhancing communication of scientific knowledge, public understanding and trust in science; and through improving science-policy interfaces at all levels.

Engineering standards can also play an important role. Policymakers need to understand the important role that engineering standards can play in governance and in enabling the buildings and infrastructure needed for the SDGs.

Principles for inclusive data governance

As artificial intelligence permeates everywhere, the market pays sharp attention to decentralized governance to feed data to machines. However, the new governance around data makes it complex to re-balance human dignity with financial benefits, thereby losing human beings' fundamental rights in the new economy. Three principles for inclusive data governance are essential: fair data, transparent algorithms, and trustworthy architecture.

New regulatory needs for a sustainable digitalisation

Digitalisation leads to entirely new products and services with entirely new characteristics that require specific regulatory solutions. Examples include the following:

Human digital twins - which are the aggregation of human related data that represents its real counterpart in the virtual world- entail a range of ethical dilemmas.

Central bank digital currencies appear to become the next step in the evolution of digital currencies after the Bitcoin and stable coins. At the end of 2020, 86% of central banks explored the issuance of such currencies. Banking the unbanked and improving financial inclusion are among their main promises. However, such currencies may also deepen the digital divide and have spill-over effects in developing countries. A multilateral platform for reflecting on the design of digital currencies could be useful but would need to include affected stakeholders.

Digital labour platforms have generated new job opportunities in developing and developed countries, but often fail to provide decent work when existing labour regulations do not cover these new activities.

Large untapped potential of digital consumer innovations

Indicative data for 2020 show that with respect to digitalisation and AI we continue on a "business-as-usual" trajectory. A wide range of new solutions is becoming available, albeit at the cost of new economic, social, environmental, and political consequences. In the near future, AI energy use is expected to increasingly compete with other uses. In response, we need to strategically support digital consumer innovations for a rapid increase in energy and materials efficiencies.

Fortunately, there is large untapped potential of digital consumer innovations in mobility, food, buildings, and energy services, which could be readily deployed worldwide at a level commensurate with a global "best-case scenario". These innovations could radically transform global service efficiencies, opening up more feasible pathways towards the achievement of the SDGs, good living standards and the agreed climate goals everywhere.

Cooperative, near-term actions need to be taken for transforming service efficiencies, commensurate with a sustainable and resilient recovery from the COVID-19 pandemic towards the achievement of the SDGs.

AI progress is rapid and has already surpassed human cognitive capabilities in narrow specific tasks

AI has rapidly progressed at an accelerated pace. "Deep neural networks" now surpass human cognitive capabilities in narrow, specific tasks, such as facial recognition, medical radiological diagnosis, and many others. In fact, narrow AI has become ubiquitous in many countries – unbeknownst to many. At the same time, billions remain excluded from AI's benefits. Performance and capabilities grow at exponential rates, leading to new applications, new development models, and also sustainability concerns. This has important implications for humanity's aspirations expressed in the SDGs. However, future predictions are highly uncertain, which is particularly challenging, since the current AI transformation appears to proceed about seven times faster than the industrial revolution in the past. Unless the issue gets addressed, new socio-economic divides will continue to arise with deeper gaps from unequal ownership over the AI and other digital technologies.

No official statistics exist for the computing power of all the world's computers, smart phones and other devices – most of which are connected to the Internet. This collective global computing power was estimated to have reached 93 million Petaflops in March 2021, the equivalent of 4.7 million human brains. By 2030, we might reach an estimated 150,000 Zettaflops or the human equivalent of 7.7 billion human brains – basically a doubling in human cognitive capacity.

Learning from science-policy assessments

Syntheses of science-policy assessments are important to enable informed and integrated decision-making in relevant time. While UNEP made a big step in this direction with its report, entitled "Making peace with nature: a scientific blueprint to tackle the climate, biodiversity and pollution emergencies", major knowledge and assessment gaps remain with regard to digitalisation and other related frontier technology clusters.

An IPCC-style, in-depth assessment of digitalization and of some of the key related frontier technology clusters is needed. In addition, relevant readiness assessments across disciplinary lines should be regularly synthesized to explore synergies and high-impact actions.

Many promising environmentally compatible frontier technologies

There are many environmentally compatible frontier technologies which could be deployed in developing and developed countries alike. Examples include: distributed recycling combined with additive manufacturing; highly energy-efficient AI hardware designs; low data AI; 5G in smart irrigation: exploring pathways for irrigation; biomimicry to tackle urban air pollution; robotics for monitoring the oceans; saltwater greenhouses for food production; ablative pyrolysis for sustainable energy production; and chemical technology for future plastic recycling. Knowledge and capacities are the main constraints to their diffusion. Frontier technologies themselves could be leveraged better for dissemination and knowledge transfer in this regard.

Table 2. New elements in 2021 TFM findings complementing earlier findings in 2019

Theme	Findings	Proposed actions
Previous TFM findings	2019 TFM findings remain valid, but new elements needed to be added	• IATT WS10 and 10-Member-Group to identify highest priority global actions in the nine areas.
STI importance	COVID-19 has greatly amplified the importance of STI, but it has also exposed weak institutions. The world broadly remains on a business-as-usual trajectory. Paradoxically, despite modern science's international and open characteristics, many opportunities have been missed, especially in terms better global cooperation, global solidarity, and trust in science.	• Invest appropriately into science-policy-society interfaces. Implement the many "lessons-learnt" for these interfaces (see this report) • Invest in science and education and build overall trust in science. • Highly value and institutionalize trusting relationships among policymakers and scientists • Strengthen global science cooperation for the SDGs
COVID-19 – the great amplifier of digitalisation and divides	The COVID-19 pandemic has accelerated digitalization on the one hand and greatly amplified persistent technology divides on the other hand – essentially excluding billions of people from reaping the benefits of digital technologies and innovations. It also exposed amplified the digital gender divide – the more advanced the skill, the greater the gap.	• Urgently address the persistent technology divides that have excluded billions of people from reaping the benefits of digital innovations • Urgent action to connect the remaining 3 billion to the Internet as a matter of global priority. • Support to upgrading of international Internet backbones

	Other underlying, pervasive technology trends have continued with surprising regularity, despite the COVID shock (e.g., super-exponential growth in by large-scale providers since 2017)	• Promote equitable access to Internet access and digital skills across gender and social divides. • Create roadmaps highlighting the regular long-term technology trends
Innovation acceleration in times of crises	The enduring COVID-19 crisis has accelerated innovation in medicines, vaccines, digital technologies and artificial intelligence. Our global innovation system in "normal" times has operated well below its potential. The good news is that we might be able to supercharge it in times of crisis.	• Promote mission-oriented innovation for sustainable development • Promote roadmaps with clear performance targets. • Invest much more in basic research and promote knowledge linkages between disciplines and with innovators • Establish one-stop R&D platform that links innovative actors in academia and industry
Reorienting financial stimulus packages	The world remains in fire-fighting mode. The vast majority of financial stimulus and recovery packages in response to the pandemic are not yet focused on longer term measures and sustainable investments in STI	• Consider the long-term sustainable development implications of present decisions in response to the COVID-19 pandemic. • Re-orient financial stimulus packages to a green, sustainable, R&D- and technology-focused recovery, in order to increase resilience to future sustainability crises. • Deploy AI and big data tools for "near real time" assessment and correction of decisions
Public support for basic research	The fundamental biotechnology knowledge which permitted the development of COVID-19 vaccines in record time largely originated in public and non-profit research institutions and spin-offs thereof. It was thus primarily due to public funding for basic research. Yet in the crisis, pharmaceutical companies received tens of billions of dollars to support applied research, production scale-up and population testing. No commensurate public investment increase was made into basic research.	• Acknowledge the decisive role of public funding for basic research and greatly increase such investment • Incentivize more private sector spending on R&D relieving more public sector funds to be dedicated to basic research and science
Align research priorities with SDGs	Most scientific research is concentrated in a few high-income countries and tends to focus on challenges that are not relevant to SDG challenges in low-income countries. It also typically neglects the development of frameworks and guidelines for balancing economic, social and environmental progress. The pandemic proved that in addition to "not leaving anyone behind," the world discovered the hard way that "no one can be saved alone."	• Funders, donors and international organizations should seek to steer research priorities and improve the assessment of research's societal impacts. • Dedicate more global mechanism resources for addressing challenges facing the implementation of all SDGs, including a better understanding of imbalances in progress within regions,
Many successful technology solutions in COVID response	There were many examples of effective frontier technology solutions in response to COVID-19, but their successful deployment requires skills and capacities.	• Promote capacity development and demonstration projects, public maker spaces and citizen labs.
Frontiers in vaccines and access to STI solutions	The science and technology of vaccines had already progressed significantly in recent years – long before the COVID-19 pandemic, but funding for researchers and innovators has been difficult to come by. Yet, by end April 2021, one billion COVID-19 vaccines had already been administered. How can we leverage a similar push for the 20 neglected tropical diseases? And how can access to vaccines and the technologies to develop and manufacture them be ensured? Open science and IPRs have shared values of dissemination of information, knowledge, processes, and data for enabling wider dissemination of the benefits of science, and technology for all.	• Global push to eliminate the 20 neglected tropical diseases • Align processes and key messages of open science and IPRs • Incentivize open science practices for all stakeholders • Campaign and demonstrate the great benefits for all parties and societies of open science • Promote policies and processes implications of adopting open science along with effective IP regulations nationally and institutionally.

Latecomer development opportunities in the global green economy	A worldwide, profound techno-economic paradigm transition is under way towards a greener global economy, which is driven by deliberate policy changes, creating 'green windows of opportunity' for developing and emerging economies that come with growth, jobs and employment.	• Policy makers need to deliberately bring together, otherwise distinct, policy domains, and co-design solutions. • Policies need to be sensitive to the technological specificities of the different green sectors.
Transforming science and engineering systems	The pandemic revealed deficiencies in the capacity of science systems to respond to new priorities in a timely manner, while limiting the disruption to ongoing research. Perennial issues of persistent inequalities in science and limitations of the current system of publication and peer-review were also brought to the fore. Engineering standards can also play an important role.	• Science systems must be capable of a quick response to changing challenges, while increasing quality of and trust in science and engineering. • Policymakers need to understand the important role that engineering standards can play in governance and in enabling the buildings and infrastructure needed for the SDGs. • Support the open science process
Principles for inclusive data governance	Decentralised, new governance around data makes it complex to re-balance human dignity with financial benefits, thereby losing human beings' fundamental rights in the new economy.	• Ensure fair data, transparent algorithms, and trustworthy architecture. • Support open data and government
New regulatory needs for sustainable digitalisation	Digitalisation leads to entirely new products and services with new characteristics that require specific regulatory solutions. Recent examples include human digital twins, central bank digital currencies, and digital labour platforms.	• Issue specific regulations • Provide an international platform for exchange of experiences and assessment of risks
Rapid progress of narrow AI and highly unequal ownership	AI progress is rapid and has already surpassed human cognitive capabilities in narrow specific tasks. Narrow AI has become ubiquitous in many countries – unbeknownst to many. At the same time, billions remain excluded from AI's benefits. Future predictions are highly uncertain, which is particularly challenging, since the current AI transformation appears to proceed about seven times faster than the industrial revolution in the past. New socio-economic divides will continue to arise from unequal technology ownership and access.	• The rapid changes and potential implication need to be analyzed and documented, in order to support decision-making, especially in developing countries. • Reliable AI future scenarios are needed, • Support the localized AI platforms accounting for the application context
Untapped potential energy-saving potential of digital consumer innovations	There is a vast untapped efficiency potential of readily deployable digital consumer innovations in mobility, food, buildings, and energy services.	• Facilitate and prioritize investments and coordinated actions on technology efficiency, business innovations and behavioural change to rapidly increase end-use efficiencies in energy, water and land-use. • Consider the long-term sustainable development implications of policies, plans and programmes related to digitalisation and artificial intelligence.
Environ-mentally compatible frontier technologies	There are many environmentally compatible frontier technologies which could be deployed in developing and developed countries alike. Knowledge and capacities are the main constraints to their diffusion.	• Apply frontier technologies for efficient dissemination and knowledge transfer • Strengthen innovation capabilities in societies by mobilizing learning, indigenous knowledge and new institutions that reward creativity and entrepreneurship.
Science-policy assessments	Syntheses of science-policy assessments are important to enable informed and integrated decision-making. While UNEP made a big step in this direction with its report, entitled "Making peace with nature", major knowledge and assessment gaps exist with regard to digitalisation and other related frontier technologies.	• We need an IPCC-style, in-depth assessment of digitalization and of some of the key frontier technology clusters • Relevant assessments across disciplinary lines should be regularly synthesized to explore synergies and high-impact actions

Sources: IATT WS10 on analytical work on emerging science, frontier technologies and the SDGs.

Key new UN system activities

In the last two years, many of the new UN activities in this space built on the earlier actions, some of which were already reported in 2019. For example, in 2020, the UN Secretary General launched a Roadmap for Digital Cooperation which laid out his vision for a more open, free and secure digital future for all. He also appointed a Tech Envoy. Following HLCP discussions, a new UN interagency working group on AI (IAWG-AI) led by ITU and UNESCO was launched at the end of 2020. Similarly, the UN Executive Committee established an interagency biorisk group, led by WHO and ODA. Both these groups work closely with the TFM. Discussions of frontier technologies continued at the level of the General Assembly. Most recently a high-level thematic debate on digital cooperation and connectivity was convened in April 2021. An increasing number of UN entities have refocused existing flagship reports on frontier technology issues or initiated new publications. For example, DESA included frontier technology issues in several of its flagship reports, but most recently has also worked on a Department-wide report specifically dedicated to the impacts of AI on the achievement of the SDGs. WHO, UNCTAD and UNDP launched a Tech Access partnership which initially supported access to COVID-19-related technologies but since has expanded well beyond. And there are many more such activities.

Follow-up

Rapid scientific and technological change is among us, and it is not going away. The scope and scale of its impacts, both positive and negative; and across the full range of economic, social, and environmental dimensions require us to engage actively with the issues.

Compared to previous year's updates, the COVID-19 shock has forced the task team to include a range of new issues in its findings. Many of them relate to science and how to progresses to technology and ultimately innovations. Indeed, science, technology and innovation aspects are closely interlinked. An isolated look at technology is insufficient.

The current TFM findings stand to be refined further through discussions at this Forum and beyond. They also serve to indicate a set of central areas of work, where the collaborative, multi-sectoral and multi-stakeholder context of the TFM stands to add value and advance understanding at global, regional and national levels.

When we work together – across national borders, across groups, disciplines and stakeholder groups - we as humanity can harness science and technology to the benefits for all of us, now and into the future. Indeed, this concerns all of us, in developing and developed countries alike.

It is against such background that the TFM findings are so important. It is multi-stakeholder co-operation in the service of our SDG aspirations that will make all the difference.