Emerging science, frontier technologies, and the SDGs

Perspectives from the UN system and science and technology communities

IATT Report for the STI Forum 2021

Interagency Task Team on Science, Technology and Innovation for the Sustainable Development Goals

Advance unedited report

Emerging science, frontier technologies, and the SDGs

Perspectives from the UN system and science and technology communities

IATT Report for the Multi-stakeholder Forum on Science, Technology and Innovation for the Sustainable Development Report 2021

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Executive Summary

The present report, entitled "*Emerging science, frontier technologies, and the SDGs - Perspectives from the UN system and science and technology communities*" presents the updated 2021 TFM findings on the impact of rapid technology change on the achievement of the SDGs, together with science-policy briefs, updates and other materials upon which the findings are based.

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 in this report will support this endeavor.

I. Introduction

The 2030 Agenda for Sustainable Development launched a Technology Facilitation Mechanism (TFM), which had been established by the Addis Ababa Action Agenda in order to support the Sustainable Development Goals. Member States agreed that it would "*... be based on a multi-stakeholder collaboration between Member States, civil society, the private sector, the scientific community, United Nations entities and other stakeholders and will be composed of a United Nations inter-agency task team on science, technology and innovation for the sustainable development goals, a collaborative multi-stakeholder forum on science, technology and innovation for the sustainable development goals and an online platform.*"

The technical-level work of the TFM's Interagency Task Team on Science, Technology and Innovation for the SDGs (IATT) has been carried out in dedicated work streams. In particular, IATT Work Stream 10 (WS10) focuses on "*Analytical work on emerging science and technologies and the SDGs*". The IATT brings together 45 UN entities, 9 of which are currently active in work stream 10, including DESA, UNCTAD, UNIDO, ESCWA, ILO, ITU, UNEP, UNESCO, and the World Bank. Many others have contributed on specific outputs, including UNU, ECLAC, ESCAP, ECA, OOSA, WIPO, and ICGEB.

IATT WS10 has prepared this report to feature recent perspectives from experts in the UN system and science and technology communities on *emerging science, frontier technologies, and the SDGs*. IATT WS9 also provided important inputs on STI4SDG roadmaps.

The report features contributions in the form of science-policy briefs and updates on expert activities and findings of flagship reports. This includes contributions from eleven current and former members of the UN Secretary General's 10-Member-Group of High-level Representatives in support of the TFM. Other contributions are from expert staff in the UN system (most of which are lead authors of UN system flagship reports), academics, NGOs and experts in the private sector.

Perspectives included in the report reflect on what emerging science and frontier technologies have achieved and where they have failed during the COVID-19 pandemic (chapter III). In particular, they draw lessons from the pandemic for policy and the science-policy-society interface, present selected technology solutions and case studies, and country experiences. Beyond the pandemic, other perspectives address the impacts of emerging science and frontier technologies on the achievement of the SDGs – both in recent years and looking forward until 2030. This includes contributions on science and technology policy; on digitalisation, artificial intelligence and robotics; on big Earth data; on the environmental dimensions of frontier technologies, and specific solutions and activities (chapter IV). Looking further ahead to 2030 and beyond, chapter 5 provides perspectives on elements of science, technology and innovation roadmaps for the SDGs.

The scope of the present report is vast. This is by design, as TFM experts were asked through an open call to submit science-policy briefs that highlight issues they would like the international community to consider. Hence, the choice by the entire "crowd" of contributors have set the agenda and scope of the present report. The briefs outline empirical facts/issues and present policy recommendations.

Submissions had to pass a peer-review that focused on technical aspects, readability and the scientific and engineering evidence presented. This also means that not all contributions could be accepted. However, peer-reviews did not assess political aspects or policy merits of the contributions. It is therefore important to note that the views expressed in this report are those of the authors and do not necessarily reflect those of the United Nations or its senior management. Instead, an important purpose of this report is to serve as a Forum on new ideas and suggestions that maybe considered by the TFM community.

We hope you will enjoy this report and possibly follow-up with IATT WS10 and some of the authors of the briefs on their proposals. It is what the TFM is all about – stimulating multi-stakeholder partnerships, analysis and actions on harnessing science, technology and innovation for the SDGs.

II. TFM findings 2021

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

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[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

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 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

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

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. 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)	• 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 • 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	The science and technology of vaccines had already progressed significantly in recent years – long before the COVID-19 pandemic, but funding for researchers	• Global push to eliminate the 20 neglected tropical diseases

access to STI solutions	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.	• 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 and has started cooperating Department-wide to analyse 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.

III. Achievements and failures of emerging science and frontier technologies during the COVID-19 pandemic

This chapter reflects on achievements and failures of emerging science and frontier technologies during the COVID-19 pandemic. It features perspectives of individual TFM stakeholders, including the 10-Member Group, IATT members, and other external contributors, and summarizes them. Since the beginning of 2020, many experts have worked on various aspects of this. The present report provides a good opportunity to put key findings and recommendations together on a topic that has preoccupied the UN system over the past year.

Following a brief overview of the contributions (Section III.A), three different types of contributions are presented: policy briefs on lessons from COVID-19, including on general policy issues and the functioning of the science-policy-society interface (Section III.B); on specific technology applications and case studies (Section III.C); as well as updates on country experiences, activities and news (III.D).

A. Overview

Five science-policy briefs identify lessons from COVID-19 responses for general policy and the science-policy-society interface.

Dominique Foray of EPFL in Switzerland examines the acceleration of innovation which delivered COVID-19 vaccines, medicines and many digital solutions in record times during the COVID-19 crisis, the reasons for the acceleration, and under which circumstances a similar acceleration could be achieved to find solutions to other global sustainability challenges.

Members of the COVID-19 Advisory Team to the President of the Polish Academy of Sciences, chaired by Jerzy Duszyński, draw eight policy lessons: invest in modern health care, build professional and independent expert institutions in the field of public health, provide experts with access to data, invest in science and education, build trust, work together for the common good, and learn to live with the pandemic.

Giovanni Dosi of the Scuola Superiore Sant'Anna in Italy draws policy lessons from our medical/therapeutic responses, building on his earlier work on epidemiological effects and asymmetric impacts among social classes. He noted the earlier public and nonprofit investments in basic science and genetic engineering which made vaccines possible, yet in the crisis governments gave more than US$24 billion to pharma companies (which were mostly unprepared for vaccines), with no commensurate scaling up of investment in public fundamental research. In his view, health is a universal human right and health-related knowledge should be a global common good. He calls for a reform of the present IPR systems, including provisions in the TRIPS agreements.

Kristiann Allen of the University of Auckland, New Zealand, in a joint submission by the International Science Council and the International Network for Government Science Advice (INGSA) draws four lessons from an examination of the relationship between science, policy and wider society (the so-called science-policy-society interface(s) (SPIs)): SPIs require a more sophisticated understanding of their functioning; certain key roles are highlighted by the pandemic; SPI approaches must be dynamic to respond to different policy stages and conditions of the evolving issue or set of interrelated issues; and it is important that SPIs connect nationally, internationally and globally.

Shivani Nayyar and Carolina Rivera Vázquez of UNDP present an analysis of data on a range of IT skills that enable workers and students to migrate their activities online. They find that women systematically disadvantaged in a wide range of IT skills - the more advanced the skill, the greater the gender gap. As COVID-19 caused work, education, and many aspects of human life to move into the digital sphere, it exposed the digital divide and gender discrepancies in access to quality internet, devices, and skills.

Three science-policy briefs examine specific technology applications and case studies in COVID-response.

Fouad Mrad, Patrick Saoud, Raphaelle Akhras, Youssef Chaitani, and Juraj Riecan of ESCWA draw lessons from two of their projects that apply “big data” for improving policy effectiveness – one on big data to capture living conditions of Syrian refugees in Lebanon and their host communities, the other one on using nontraditional data sources to evaluate the effectiveness of COVID-19 response policies in Jordan and Lebanon. They show how big data provided decision makers with near real-time information on the impact of the crisis and how the nontraditional data sources (e.g., satellite images, call detail records, social media sentiments) can support crisis management. They found that big data could not replace traditional sources but was a good complement which also reduced biases.

Imad H. Elhajj and colleagues at the American University of Beirut report lessons learned from the official COVID-19 contact tracing app "Ma3an". Voluntary uptake of the app has been a major constraint and the authors propose a mandate to use the Ma3an app to gain access to all closed public spaces. The authors also suggest integrating the app into a wider national strategy, a clear financial commitment from the government, and partnerships with large organizations, (e.g., syndicates, universities, companies) to encourage their members to download the app.

The UN Office of Outer Space Affairs reports on the use of space science and technology for health promotion, health protection, surveillance, contact tracing, transmission monitoring, health-care delivery in remote areas using telemedicine and tele-health services. Space science and technology provide innovative research platforms for advancing medical knowledge and spin-offs for the development of health-care equipment, operational activities and procedures. The authors provide a strong case for international cooperation in space-derived data and information.

Six contributions report on country experiences and/or provide updates on activities

Morimoto Koichi, Harayama Yuko, and Nagai Ryozo of the Engineering Academy of Japan report on results of discussions by the Academy's Committee on Post-COVID-19 Era. They review the COVID-19 situation in Japan, chart the way towards a data-driven society, highlight the need for evidence-based communications in the context of vaccination programmes, and call for strengthened international science and technology collaboration, including in terms of existing WHO, Gavi and CEPI arrangements.

The Department of Science and Technology of the Philippines outlines scientific initiatives, specific technology solutions and policies implemented by the Philippines in response to COVID-19. This includes short-term measures (testing kits, telemedicine devices, a hub for data sources and epidemiological modelling, specimen collection booths), medium-term research programmes and block grants, and long-term establishment of the Virology S&T Institute of the Philippines and Pharmaceutical Development Centers.

The Korea Research Institute of Bioscience and Biotechnology identifies key factors in the Republic of Korea's successful response to COVID-19. This includes the establishment of a government-led national response system, strategic investments in basic research and effective, combined R&D and infrastructure capabilities. As a result, diagnostic technology was developed in time to contribute to effective infection control.

Lee Hanjin and Moon Aree of the National Research Foundation in the Republic of Korea compares the COVID-19 response strategies and policies in the Republic of Korea with those in Japan, New Zealand, Germany, Sweden, and the U.K. They suggest that countries should prepare for a paradigm shift toward a non-contact society, embracing an era of digital transformation.

The International Centre for Genetic Engineering and Biotechnology reports on its efforts in SARS-CoV-2 surveillance, the development of alternative diagnostic tools, and the provision of technical expertise on COVID-19. It highlights the importance of adapting technology to local settings, removing barriers to research, providing access to STI solutions, and using affordable COVID-proof air-sanitation systems as preventative measures in schools, retirement homes, and hospitals.

And finally, Milind Pimprikar of CANEUS, Myrna Cunningham of FILAC, Simonetta Di Pippo of OOSA and other colleagues draw on empirical evidence from series of global collaborative efforts representing Indigenous communities and key actors which were launched, and undertaken during the COVID-19 pandemic, in order to create a platform for identifying challenges and opportunities for culturally relevant space-based tools.

B. Lessons from COVID-19 for policy and the science-policy-society interface

The phenomenal speed of innovation during the COVID pandemic – explanations and lessons learned from the crisis

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Abstract

One year ago, innovation economists predicted that the prospect for inventing or discovering COVID vaccines within a year was totally irrealistic (Abid Younes et al., 2020). One year after, it looks like the prediction was wrong. This policy brief discusses various reasons for the phenomenal speed of innovation during the COVID pandemic and some lessons learned from the crisis in the area of science and innovation policy.

If we want to analyse the crisis as stimulant to innovation, we should first distinguish two types of crisis.

On the one hand, *enduring crises* for whose resolution innovation will play a central role (health crisis, climate crisis). Innovation thus occurs during the crisis.

On the other hand, *crises that represent an isolated event*, an accident, a disaster that could not be avoided. Innovation consequently occurs after the crisis to prevent such a thing from happening again (Fukushima, the terrorist attacks of 11 September).

In all these cases, crisis plays a role in accelerating innovation. But not only does it influence the rate of innovation, it also affects the direction it takes – in other words, the crisis will highlight certain areas of innovation that had been abandoned or neglected. This was very obvious for example in the case of the terrorist attacks of 11 September. Subsequent innovations in the defence and security sector clearly changed direction. They concerned mainly the field of intelligence rather than the traditional areas of defence R&D[1].

Logically, the role of accelerator seems even stronger while the crisis is underway, it lasts and innovation becomes the essential mechanism that would allow it to be brought to an end. This is of course the case with the present health crisis that I would like to look at in more depth as innovation accelerator.

The health crisis and innovation

In this case, we can consider that there are three factors that make this crisis exceptionally powerful and productive as innovation stimulator[2] :

- the benefits for society of innovations that would allow the crisis to be brought to an end are enormous. Economists will say that the social return on investments devoted to the desired innovations (in this case, vaccines) is huge. Moreover, these innovations will not create any losers because they don't substitute to any products or services already in place. There is nothing to be replaced, no creative destruction;
- the speed of the innovation is absolutely decisive. The problem is not so much inventing a vaccine but inventing it now;
- and last but not least, we know what we're looking for, we know what we want. There is practically no ambiguity or uncertainty or even disagreement about the fact that the decisive innovation is the vaccine(s) that will make it possible to immunise the entire world population.

These three factors, combined, act as a powerful driving force and have resulted in an incredible acceleration of the rhythm of innovation in a domain (vaccines) where the latter is traditionally much slower and the economic

[1] National security intelligence in the antiterrorist era involves the gathering of information on terrorists (masterminds, operatives, and supporters), their modes of operation and sources and channels of finance. Intelligence broadly means the reduction of uncertainty. R&D aimed at providing better intelligence capabilities is therefore very different from the traditional defence R&D domains (dealing with the costly development of big weapon systems such as new jet fighters, nuclear subs, long-range missiles, etc.). What is required then is the setting-up of R&D programmes that would support the development of sensory computer interfaces for detection and intelligence gathering and computer technologies for massive data analysis (Trajtenberg, 2004).

[2] Here we will not discuss the fact that this health crisis has caused an economic crisis – which is on the contrary a restraining factor regarding innovation, mainly in sectors not concerned by the innovation opportunities created by this crisis.

incentives for private actors to invest are considered low[3].

These factors have succeeded in disrupting the research and innovation routines of the pharmaceutical sector – leading to the results we have witnessed being obtained in record time[4]:

- The big laboratories have made a tremendous effort, whereas normally they prefer to commercialise treatments rather than vaccines (since by definition the vaccine eliminates the treatment markets) (Kremer and Snyder, 2015)
- The innovation phases (clinical trials) have overlapped and evaluation of the results of these trials has taken place continuously
- The public sector and governments have made major contributions (70% of the clinical trials have been financed by the public sector) (Agrawal and Gaulé, 2021)

The three factors that I have mentioned (huge social return for all, speed, we know what we're looking for) have thus boosted the innovation system of the pharmaceutical industry, obliged it to transform itself, reconfigure itself and prepare itself *for battle* in order to meet this challenge and *succeed*.

Some lessons

The first lesson is therefore that *the enduring crisis* is a powerful driving force for innovation, an opportunity to change an industry's routines and habits and reveal the irrationality of strategic behaviours that previously seemed rational (big pharmaceutical firms do not invest in vaccine research). The example of the Second World War can be taken as another case illustrating the same characteristics of an *enduring crisis*: under the aegis of the Office of Scientific R&D in the United States incredible breakthrough innovations (radar, penicillin, atomic bomb) were produced within a very short timeframe. There again it is the preparation for battle of the industries concerned that made these successes possible (Gross and Sampat, 2021)[5].

The second lesson is that, in times of crisis, what matters are not the inventions, the proofs of concept or demonstrations of feasibility, but the products capable of resolving the crisis. As an American scientist commenting on the American mobilisation for innovation during the Second World War declared – "the time for basic research is before a crisis, and urgency meant that the basic knowledge at hand had to be turned to good account" (Conant, 1947, cited in Gross and Sampat, 2021). In the case of the COVID vaccines – the invention is one thing, and the production and distribution of the products is another. We can clearly see that this second dimension was not really assessed at the beginning and therefore that the time gained by R&D was partly lost by the time periods necessary for the development of the necessary production and distribution capacities.

The third lesson comes from the comparison between the speed of innovation in the case of the health crisis (taking into account the nuance concerning production) and the relative slowness of innovations in the case of the climate crisis; another *enduring crisis*. This disparity between innovation rhythms is in fact quite easily explained. None of the three factors previously mentioned has the same force:

First, of course the benefits for society of green innovations are huge but in most cases there are winners and losers: climate change innovation must compete with existing technologies in energy or transportation and any success of an innovation will have significant domestic and international redistributive consequences.

Second, because the stress the crisis imposes on society is less intense – the perception of imminent danger is less significant – therefore the speed of innovation as crucial objective does not represent such a heavy burden as in the health crisis.

Last but not least, what must be done in terms of innovation to resolve the climate crisis is far less obvious : there is no vaccine, no single solution but multiple courses of action and options which may moreover be mutually contradictory ; courses of action that furthermore involve society as a whole. The solutions to the climate crisis lie only partially in the

[3] Economists cite a certain number of structural factors to explain this disincentive to invest in vaccine R&D, especially the fact that treatment innovation is by definition more profitable than prevention innovation, as well as the anticipation of private innovators that they will be unable to fix the desired price (because of all sorts of economic and political pressures that inevitably arise when public health matters are concerned).

[4] We must not of course neglect the role of a more traditional factor in the pharmaceutical industry, which is that of basic research that for years has been preparing the revolution of new types of vaccine.

[5] This first lesson also challenges the argument of certain economists (including the author) according to which, in the words of Rosenberg (1992), "innovation can't be planned".

engineering sciences domain – unlike a vaccine-type solution.[6]

This third lesson leads to an essential question concerning innovation policies. How to transpose innovation policy in times of crisis – which has really shaken economists' certainties regarding the way in which innovation could function in the pharmaceutical industry and what could be referred to as the elasticity of science (Myers, 2019)[7] ? How to make certain sectors "ready for battle" in all the other domains where urgent societal needs remain unresolved – from neglected diseases (again questions of vaccine but in most cases much less triumphant) to world food security, climate change, etc.

Thanks to the health crisis, it has been demonstrated that an innovation system – research, private sector and governments – is capable of transforming itself and preparing for battle very rapidly in order to produce unbelievably positive results in such a short time. As suggested by Agarwal and Gaulé (2021), one conclusion could be that in "normal times", the global innovation system may be operating significantly below its potential[8] and only crises, in their role of stimulating innovation via the three mentioned factors, can push the system sufficiently to fully realise its innovation potential.

It is therefore possible to accomplish this kind of exploit but it happens only too rarely, hardly ever even. The reason is that the three factors stated, which have played such an important role in the success of innovation during this health crisis, never apply with the same intensity.

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[6] Here we encounter the famous question – more topical than ever – posed by R. Nelson (1970) –– at the time of the first Apollo missions : "If we can land a man on the moon, why can't we solve the problems of the ghetto ?" This question is intended to highlight the contrast between a great problem whose solution involves solely the engineering sciences and a great problem whose solution involves numerous domains, particularly social ones (see also Nelson and Sarewitz, 2008).

[7] Economists would argue that in the short run the efficiency of a huge re-allocation of funding to a specific scientific domain is limited because only a subset of researchers have the right human capital to advance the knowledge frontier in the considered area. And the supply of adequate human capital in terms of both quality and quantity is very inelastic in the short run. Human capital is not the only barrier: good research ideas may also be scarce. In a world of scarce ideas, increasing funding invariably leads to diminishing returns (Abi Younes et al., 2020). But all these arguments concerning the inelasticity of science have thus been swept away by the facts!

[8] This is why decades or more are needed to develop certain kinds of vaccines for certain kinds of markets.

Lessons from the pandemic: strengthen health care, invest in science and education, and build trust

Members of the COVID-19 Advisory Team to the President of the Polish Academy of Sciences

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Introduction

Since the outbreak of the pandemic, many breakthrough discoveries have been made, including the development of the COVID-19 vaccine, which has turned the containment of the pandemic into a realistic goal. In order to accomplish this goal, however, we must learn the lessons of what we have found out about the state and its institutions, as well as about ourselves. We can already draw two fundamentally important conclusions. First of all, to tackle the challenges posed by the pandemic, we must have a robust health-care system and independent institutions responsible for collecting and analyzing data on epidemic threats, and we must invest in science and education. Secondly, we must strengthen solidarity in society so that its members follow the standards of safe behavior, work together, and take action for the public good.

Robust and independent institutions are needed

Lesson 1: Invest in modern health care

The pandemic has laid bare the weaknesses and shortcomings of the health care system. If it had not been for extraordinary dedication on the part of medical professionals, the toll taken by the virus would have been far greater. The absence of strategic preparation, sudden organizational changes, staff shortages worsened by the pandemic, shortages of basic personal protective equipment and beds with ventilators and access to oxygen, significant reductions in the availability of non-COVID-19 care, and long wait times for health-care services all show that Poland's health system was and still is dramatically unprepared to deal with the pandemic and needs profound reforms.

In the short term, improving the functioning of the health system requires better planning and communication in hospital management. In the long run, it will be necessary to increase the number of medical professionals and provide adequate funding. Today, public funding for health care in Poland accounts for about 4.5% of GDP[1]. This is not enough. The EU average is nearly 8% of GDP, with such countries as Germany and Sweden spending over 9% of their GDPs on this goal. Underfunded health care means a low quality of life for citizens. Health-care services are not a bottomless pit, but one of the best investments in the prosperity of the state and the well-being of its citizens[2].

Lesson 2: Build professional and independent expert institutions in the field of public health[3]

The pandemic has also exposed the weakness of epidemic prevention and control institutions, including staff shortages, as well as insufficient organization and

[1] Eurostat, Expenditure for selected health care providers by health care financing schemes (2020) http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_sha11_hphf&lang=en

[2] Hendren, N., Sprung-Keyser, N., (2020) A Unified Welfare Analysis of Government Policies, Quarterly Journal of Economics, Vol.135, I:3, 1209-1318

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management of data on infections. Acutely felt examples include the lack of adequate research and modern epidemiological models dedicated to the needs of public health. In this respect, many countries have independent public health institutes. For this reason, the emergency management system in Poland operated without access to necessary information and without a long-term strategy. It is necessary to establish a network of independent and interdisciplinary expert teams or institutions that would provide reliable analyses for public health purposes. Such a system of independent experts and institutions improves the monitoring of the authorities by the public and ensures that the actions being taken are transparent and rational[4]. Recommendations made by independent experts and scientists as well as representatives of universities and research institutes should therefore be a permanent element of the state's activities taken in response to and during epidemics.

Lesson 3: Provide experts with access to data

Administrative resources and research data should be made available in a structured manner with clear policies on their usage, optimally in the form of a public repository. Such resources require data quality control, effective management, and coordination. The scientific community and those responsible for IT systems in health care should work together to find a suitable solution. Source data and research findings should be made available to the public. Professional data collection and transparent access policies would make it possible to use the experience and knowledge of external experts.

Lesson 4: Invest in science and education[5,6]

The pandemic has made us see the importance of science and decisions based on the results of scientific research. For this reason, scientific research, especially in the area of public health, should be treated as a priority and should receive adequate funding. It is likewise necessary to take action to build confidence in science, for example through clear communication of research findings to the public. Also, the public must be made aware of the fact that scientific knowledge is constantly evolving, and discussions and disagreements are something normal and beneficial in the world of science, because they bring us closer to the truth.

The pandemic has made us aware of the importance of education for the proper development of humans and society. The adverse psychological and educational effects of long-term school closures on children and adolescents may be very serious and last much longer than the pandemic itself. They will most likely affect the public's mental state and competences in the future[7]. Experts agree that school closures should be the last measure to be adopted, after other restrictions are implemented[8].

The pandemic has also demonstrated that the weakness of Polish school lies in the curriculum overload, the rigid system of education, and the focus on the conveying of information. The Polish education system has been unable to cope with the pandemic, and this fact has an adverse educational impact on children. Education is the foundation of today's knowledge-based economy.

A solidary-based society is needed

Lesson 5: Build trust[9]

People must trust institutions and one another and the government must trust society for a success to be achieved not only in the fight against a pandemic, but in the conditions of any crisis. The competence of the government authorities and public institutions, in turn, is the key condition for building this trust. "Politicizing" the virus, taking action to deliberately create conflicts, showing arrogance, and ignoring the rules imposed on the rest of society have all led to the fact that the second wave of COVID-19 infections in the fall had such tragic

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consequences in Poland. We did not even get a passing grade on this test, and we are about to face a third wave.

The less people trust the recommendations formulated by the government institutions, the worse the expected outcome of the fight against the pandemic. Separating the debate about the pandemic and the decisions made by public administration bodies from ongoing politics will help to increase trust. We should monitor the actions of politicians and vote for those who are able to keep health care and current politics separate.

Lesson 6: Work together for the common good[10,11]

The pandemic has also taught us that working together is important in every sphere of our lives. In the economic sphere, it is necessary to formulate fair rules for the distribution of protective equipment and vaccines. In the political sphere, we need involvement in the development of fair solutions in the EU and across the globe so that national and global goals complement each other. In the social sphere, individual protective efforts will not be effective if others ignore them. Only together can we defeat the virus. This also means that we should look after the underprivileged, minority groups, and those at risk of social exclusion to a greater extent than before.

During the pandemic, we have learned how much depends on our behavior, even if institutions are ineffective. We can eliminate many uncertainties and threats by strictly following the recommendations, mostly by acting in keeping with the simple rule known as DDM (distance, disinfection, and masks). But we must show solidarity in these actions – in the interests of not only all of us as a group but also each of us individually.

Lesson 7: Learn to live with the pandemic

The COVID-19 pandemic will stay with us for a long time to come. We must learn how to live with the virus and stay safe. We should therefore create innovative solutions in the public sphere. Based on what we know today, the COVID-19 vaccine offers effective protection against symptomatic COVID-19 infections. In order to prevent the transmission of the virus, we may be required to keep appropriate social distance for a long time. Therefore, those who construct, design, and organize public life should find innovative solutions regarding means of transportation, public institutions, and personal protective equipment that will allow compliance with epidemic prevention and control recommendations without being overly burdensome for social life. Enormous European resources available under the recovery fund should support such innovations.

Lesson 8: Make political choices with long-term goals in mind

The pandemic has highlighted the weaknesses in society, leadership, and state institutions. Now is the time to learn our lessons. Failure to do so will cost us dearly in the future. We should engage in a debate on such important issues as health care, education, and science. We should evaluate politicians and their platforms based on concrete proposals to improve the situation in these spheres of public life.

Further reading: The team has produced several position statements, and a report entitled "Understanding Covid-19".

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Some policy lessons from medical/therapeutic responses to the COVID-19 Crisis: A rich research system for knowledge generation and dysfunctional institutions for its exploitation

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It is useful to distinguish between the direct and indirect impact of the COVID-19 pandemic. The former includes the epidemiological effects. We try to model them in Bellomo et al. (2020). The latter concern the effects of the institutional and policy responses to it. In turn, among such effects one may further distinguish the socio-economic impact of the measures of containment and mitigation. We discuss them with their deeply asymmetric implications among social classes and groups in Dosi, Fanti and Virgillito (2020). Finally, there are the medical/therapeutical responses. This note concerns them.

I shall, first, present some major "facts"; second, discuss some general lessons; and, third, offer some policy implications.

Some medical/therapeutical facts revealed by the pandemic and the policy responses to it

(i) A few months after the identification of the Covid-19 virus at least seven vaccines have become available (Pfizer, Moderna, Astrazeneca, Sputnik V, Johnson and Johnson, Sinopharm, Sinovac, Covaxin) and at least six others will be very soon (Curevac, Novavax, Convidicea, EpiVacCorona, and, from Cuba, Soberana and Abdala).

Normally, a vaccine takes years of research, development and testing. The quick results witness the availability of an extremely rich body of knowledge waiting for its therapeutic exploitation. It relates to several avenues of explorations, with already around sixty potential vaccines in the pipeline as of January 2021 (a thorough discussion is in Rawat et al, 2021). Many of them, but not all, are broadly associated with the Genetic Engineering paradigm, and, more specifically in our case, often associated with immunotherapies for cancer. And, indeed, some of the new vaccines (Pfizer, Moderna) were obtained by imaginative re-applications of mRNA studies originally concerning cancers.

(ii) Equally striking is that such knowledge is largely originated in public or nonprofit institutions (Oxford University, MIT, Harvard, Gamaleya Institute, University of Mainz, public Cuban laboratories, etc.) and explored either there or in spin-offs thereof (e.g. BioNTech, Moderna).

This should not be surprising. Basic research is almost entirely supported and often also performed by the public sector in both Europe and the USA. So, for example, in the USA, *all* 210 New Chemical Entities (NCEs) approved by the FDA in the period 2010-2016 got funding, to different degrees, from the National Institutes of Health (NIH) (Cleary et al., 2018).

Symmetrically, there is longer-term evidence that the private sector (essentially Big Pharma) decreased its investment in basic research, as witnessed by the diluted output of scientific papers cited in patent applications (Arora et al. 2018).

Therefore, it is not surprising that Big Pharma has been found largely unprepared, at least concerning basic knowledge on vaccines. Among the New Molecular Entities approved by the Food and Drug Administration (FDA) since the year 2000, less than 6 % concerned antibiotics or anti-viral drugs (Walker, 2020). And attention to vaccines has always been low. Even the Public/Private Initiative concerning AIDS vaccines which had raised many hopes (cf. Chataway et al., 2007) failed. Vaccines for AIDS, or later Ebola were never developed. After all, they concerned "special groups" or poor populations. It is more rewarding to invest in cures which ideally make chronic otherwise acute diseases (*docet* the anti-retroviral drugs for AIDS). But, of course, the business is different for a virus which is quite egalitarian in terms of national per capita incomes and social classes (of the infected, not of the casualties).

In this case, the whole private sector has immediately been eager to undertake focused applied research, production scale-up and population testing in exchange for an enormous amount of financial transfers. Approximate estimates suggest 8 billion euros from the European Union and around 16 billion US$ in the States. Nobody knows exactly for what: Research?

Manufacturing? Testing? Advance payment of the vaccine themselves?

Come as it may, even the developed Western societies ended up so far rationed in the vaccine supply – with the exception of the USA and Israel , let alone the disastrous conditions of the developing world – with the exception of India, which, incidentally, produces around 40% of the world vaccine supply.

(iii) The "political economy" of the public-private relationship revealed by the policy responses to the pandemic generally highlights governments and regional institutions most often (voluntarily?) hostages of Big Pharma, at gun point. The few countries not rationed have been those giving up any bargain ("Tell me what you want and I will give it to you, and more…"), even at the expense of others, with even the EU loosing despite signing pathetic contracts of the type "I will do my best to deliver, if nothing adverse happens…".

Here, we are well beyond the "regulatory capture": it is the reversal of the relationship between the State and the private actors, enshrined even in the most pro-market constitutions.

The Developing Societies are, by and large, in much weaker conditions, often lacking any competent, incorrupt bureaucracy – decimated in its number by the policies stemming from the "Washington Consensus", but not improved in its integrity. Only a few out of them have the manufacturing capabilities to make vaccines under license, and even fewer feel the political power to invoke articles 27, 31 and 73 of the TRIPS agreements permitting exceptions to IPR sales with compulsory licenses in the case of health and security crises.

(iv) Last, but not least, the pandemic crisis has dramatically highlighted the damages of the neglect, or, in some countries, the retreat by the State of a *universal public good*, *health*, and the corresponding extension of the market domain (more in Nelson, 2005).

The scenes of serious patients unable to reach hospitals is unfortunately common in developing countries, but the pandemic has shown the policy-induced scarcity of public services also in developed ones. Even in the "civilized" Europe, the author of these notes will always remember the long trail of army trucks bringing the bodies of the victims of such market-inspired negligence to crematories in other regions because burning was at full capacity in Lombardy.

And some general lessons

(i) This pandemic will not be the last one. It is a profound sign of the changes in the relationship between human kind and nature which occurred after the Industrial Revolution and rapidly accelerated over the last half century. Some scholars go as far as saying that we have entered into the *Anthropocene* (Coriat, 2020; Crutzen, 2006).

For sure the destruction of biodiversity, the elimination of any distance between wild and human habitats, the exponential increase in the industrial farming of animals – such as poultry – are all recipes for culture of viruses and bacteria mutations and their quick transmission to humans.

(ii) Even if vaccines are an ex-post mitigation and not a long-term answer, advanced societies, let alone developing ones, turned out to be largely unprepared.

The fundamental reason is the deeply dysfunctional relationship between the private and the public in the generation and exploitation of innovative knowledge, in our case of health-related knowledge.

And, in turn, the dysfunctionality rests upon the extent, depth and distribution of Intellectual Property Rights.

In brief:

(a) The Bayh-Dole Act (1980) in the USA, and imitations in other countries, including the EU, -allowing patentability of the outcome of publicly funded research -, tends to distort the efforts of search of e.g. universities, which should be mainly *curiosity-driven*. (Fortunately, the evidence supports that, at least in top universities, such distortion has not been too deep, but the risk is always there).

(b) As a cascade, public institutions generate promising "basic" knowledge which is then sold generally at ridiculous prices to Big Pharma or incorporated into spin-offs which might generate enormous rents to successful academics.

(c) At the end, it is the public which continues to support fundamental research, while it is ultimately Big Pharma which masters *the rates and directions of innovative activities*.

(d) Finally, drugs and vaccines are sold back, directly or indirectly, to the public at prices which have little to do with either the *private* costs of search or the costs of production.

(iii) It is often said that against the "the fight against the pandemic is a war". If it is, and I believe it is, *wars are too serious a business to be left to the markets.* During WWII, the USA had become, for very good reasons, a nearly full centrally planned economy. After roughly three months after Pearl Harbor it was capable of producing circa a tank per hour. Conversely, after the Covid outbreak California received with delays a largely insufficient number of *faulty* testing kits; after three months the Italian government was unable even to map who was able to produce masks (personal experience) ; all over the developed West ventilation emergency devices have been scarce for months ; and the list could continue…

Some policy lessons

Some of them, the most fundamental, are long-term.

The 'illusion of control over nature', and the use of *nature as a sink* (Brock and Taylor, 2005) has to be reversed before it is too late: putting it in a shorthand, burning forests in the Amazon and destroying rainforests in Indonesia is closely related to the health of humankind.

Equally important, health has to become a *universal human right*, and knowledge concerning health is a *global common good*.

Operationally:

(i) The crisis has shown the deep pitfalls of a health system partly or nearly fully left to the market. If health is a universal right, this must be taken care of by the public as much as, say, justice or public security.

(ii) On the contrary, even when there is a universal health coverage, like in most European countries, public hospitals have been often the prime victim of austerity policies. This must be urgently reversed. What is needed is a massive increase everywhere in the world of the overall public expenditure for the health system and the strengthening of local hospitals and laboratories: a capillary hospital system is able to cope with widespread diseases.

(iii) Basic health-related research is part of a "global war mission", thus *not* subject to the mean calculation of "cost-benefit analysis" by economists!

(iv) The States have to gain/recover the knowledge of what is produced, and what is "potentially known" in the country, and by whom (This is needed for even timid forms of 'indicative planning').

(v) During crises like the current one it should be obvious that vaccines have to be made available to the entire population of the world. A necessary condition is the possibility of manufacturing it everywhere one is capable. This in turn demands *generalized compulsory licensing*.

More fundamentally, in the near future, it is crucial to reform the prevailing system of protection of Intellectual Property Rights (IPR) and its international projection via the TRIPS agreements within the World Trade Organization (WTO). As we argue at greater length in Dosi and Stiglitz (2014), it is bad for science in Developed countries, for Global science, and for the economies of both developed and developing countries alike. It has been designed not to maximize innovation but rents for those who have had the good luck of receiving a patent (and the two are not the same).

While the evidence that IPR *in general* promotes innovation is far from convincing, there is good evidence that there may be adverse effects, especially with poorly designed "tight" IPR regimes: access to life-saving medicines may be restricted and so too access to knowledge that is necessary for successful development, and even for follow-on innovation. As governments have to spend more money to purchase the drugs they need, because of reduced availability of low-cost generic medicines, other expenditures—from those necessary to promote growth to those devoted to alleviating poverty—are reduced. Conversely, there may be perverse links between IPR protection and income distribution.

In some circumstances, such as in the pharmaceutical industry, the evidence is particularly striking. Before TRIPS, generics obtained under loose IPR regimes were able to dramatically reduce the cost of drugs available to developing countries. A vivid illustration concerns antiretroviral drugs against the HIV virus where generics were able to reduce the cost by between 98 per cent and 70 per cent. (cf. Coriat et al., 2006; and So et al., 2014).

Especially in the case of pharmaceuticals, where patents are indeed a major mechanism of rent appropriation, I propose that the public, which, to repeat, finances and performs most of the Phase I of research, ought to move all the way to phase III (i.e. experimentation on humans), and when successful, transfer to Big Pharma, on nonexclusive base, the license to produce – which at that point should yield costs and thus prices not be too different from marginal costs.

There would be three major gains.

First, the public would regain the control over the search priorities, that is on the rates and directions of innovative activities.

Second, it would certainly be a reform at massive *negative* costs for the collectivity.

Third, it would be a major equalizer in the access to lifesaving drugs between developed and developing countries.

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Lessons learned from Covid-19 for the Science-Policy Society Interface

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Abstract

The collective global experience of the Covid-19 pandemic has provided an unprecedented opportunity to examine the relationship between science, policy and wider society in what is often called the science-policy-society interface(s) (SPIs). Navigating a novel pathogen and its ensuing pandemic has dispelled some of the most common misperceptions about SPIs and revealed some relevant truths. At least four lessons can be drawn: (1) SPIs require a more sophisticated understanding of their functioning; (2) certain key roles are highlighted by the pandemic; (3) SPI approaches must be dynamic to respond to different policy stages and conditions of the evolving issue or set of interrelated issues; (4) it is important that SPIs connect nationally, internationally and globally. These lessons are all the more important for future preparedness as a pandemic such as COVID-19 and the associated health responses intersect with climate and other environmental-related pressures and underlying socio-economic disparities within and across countries.

More sophisticated understanding

The pandemic has forced the retirement of any notion of 'the SPI' as a stable relationship between science and policy, engaging solely in the linear transfer of knowledge from experts to policy makers (Palmer, Owens, and Doubleday, 2019). If it were only a matter of one side conveying evidence and the other side acting on it, we could reasonably expect almost perfect policy convergence on pandemic responses among countries, all facing the same pathogen. Instead, national, sub-national and supra-national responses have diverged widely based on different interpretations of the problem and how to address it. Some governments have prioritized economic functioning, while others took a classic public health approach, which itself varied from 'flattening the curve' to eliminating the virus. These choices were shaped by how actors interpreted their contextual conditions. Almost all choices have been contested.

This experience has cemented a more sophisticated view of SPIs, especially within the Western democratic tradition. Well-functioning SPIs should be dynamic ecosystems of organizational arrangements and processes that serve to structure the relationships of diverse actors around complex policy problems like pandemic response. As the range of actors brings a plurality of perspectives, SPI processes must help facilitate the exchange of scientific evidence and place it in the context of surrounding (sometimes opposing) social values (Douglas, 2009). By doing so, they create the conditions for evidence-informed policy options to emerge, with high credibility and social legitimacy (van den Hove, 2007; United Nations Environment Program, 2017; Weingarten, 1999)

Key roles within SPIs

We tend to think of this work taking place in formal government settings such as Panels, Advisory Committees or other institutional structures operating as 'boundary organizations' (Gustafsson and Lidskog, 2018; Guston, 2001; White, Larson, and Wutich, 2018). But the pandemic also has revealed the role of SPI mechanisms outside of government (e.g. high-profile individual academics and science journalism, etc.) in influencing policy consensus and promulgating ideas. Whether formal or informal, the experience of pandemic has served to illustrate and affirm that boundary roles in the SPI ecosystem are distinct from the conventional scientific work of research, publication and dissemination (Gluckman, Bardsley, and Kaiser, 2021; Pielke, 2007). They include:

1. scientific knowledge generators: researchers and technical experts
2. scientific knowledge synthesizers: with specialized skills in knowledge integration and meta-analysis

[1] This submission was inspired by the Committee of Experts on Public Administration's (CEPA) Guidance Note on Science Policy Interfaces, which was authored on behalf of CEPA, by the authors of the present submission. We recommend that this submission be read in conjunction with the CEPA guidance note https://publicadministration.un.org/Portals/1/Strategy%20note%20science%20policy%20interface%20March%202021.pdf

3. scientific knowledge brokers: those who work as multidirectional conduits between SPI stakeholder groups

Science communicators.

Some boundary organizations will have practitioners in each of these roles, especially organizations that specialize in certain sectors of public policy. More often, however, the roles will arise from different parts of the SPI ecosystem and need to coordinate their efforts deliberately. This is especially true during a crisis like Covid-19. For instance, ministries of health have most often coordinated these roles, including working with specific academics and science communicators outside of the ministry.

Different approaches for different stages and conditions

The experience of the unfolding pandemic has also offered a unique view of how SPIs are mobilized in different ways at different stages of the crisis, depending on the types of decisions and actions needed. At the outset, when treatment and prevention drugs were unknown and ICU protocols were only emerging, the best tools available were the behavioural measures of public health (i.e. social distancing and increasing mobility restrictions, masking, hygiene). This approach demanded collective action, which in turn required careful science communication to the public, informed by the social and behavioural sciences, as well as community input. The latter has been especially important in the context of multi-cultural communities.

Such behavioural restrictions wear thin quickly, however, and more comprehensive pandemic responses emerged as the pandemic, knowledge of the pathogen and the efficacy of measures all evolved. Responses have been based on how officials have interpreted new knowledge and the evolving threat within their socio-political and material contexts. It is in this interpretation that the interplay of scientific knowledge and normative public values within SPIs is best illustrated (Wesselink and Hoppe 2020).

We have seen the Covid-19 threat constructed (framed) in many different ways, each with different sets of consequences (e.g. as primarily an economic threat, a threat to personal autonomy, a threat to specific sub-populations, to mental health, etc.). All of these are valid concerns, but the relative emphasis has varied across time and place. At times, SPIs must adopt iterative processes that enable consensus on the framing and structuring of the problem (or set of interrelated problems) so as to synthesize evidence from multiple, and sometimes competing, perspectives (Mair et al., 2019; OECD, 2020; Stevance et al., 2020; Wesselink and Hoppe, 2020). To this end, the key functions of SPIs at various stages include:

1. <u>problem framing:</u> defining the nature and extent of the problem, in a collaborative way and informed by evidence
2. <u>problem structuring</u>: minimizing disagreement and uncertainty in the nature of the problem and the nature of the knowledge needed for action.
3. <u>knowledge selection:</u> determining relevant knowledge needed for problem structuring and designing solutions; involves integration of various disciplinary knowledges and reflection on possible hidden biases
4. <u>Managing relationships between stakeholders:</u> structured processes that protect the integrity of the science while preventing strict technocracy.

Covid has exemplified the need for agile SPIs that can move through these functions as real time data and information shed new light that can prompt reframing, restructuring or seeking new types of knowledge to inform policy options anew in quick learning and adaptive iterations.

At the same time, the pandemic has also demonstrated that linear processes of knowledge sharing do have a place in well-functioning SPI strategies. For instance, when there is consensus on policy directions (to 'flatten the curve' for instance), a more direct and linear process of evidence provisioning is still an important SPI function. Evidence-informed modeling and analysis aimed at characterizing the extent of the threat or impact in different populations or testing different policy variables is invaluable intelligence to optimize the policy response.

Connecting SPIs vertically and horizontally for better policy coherence

Both the iterative and linear processes of SPIs are made more effective when they are connected horizontally across sectors and across levels of government vertically. The pandemic's deep and pervasive disruption has demonstrated the systemic nature of nearly all socio-economic activity. No matter which sector is prioritized within the pandemic response, there are ripple effects across all sectors, which require cross-sectoral collaboration to fully examine and accommodate. Involving experts with different sectoral expertise has helped to mitigate the tradeoffs. For instance, the International Public Policy Observatory in the UK is a newly established boundary organization designed to help policy makers apply systemic social science insights to help mitigate the impact of the pandemic.[1]

At the same time, connecting SPIs internationally and globally is just as important as connecting intersectorally. Policy trackers and observatories have proliferated since the outset of the pandemic[2]. This is one way for policy makers to source policy ideas to apply domestically. However, when experts can also share underpinning evidence as well as a common position on what to count as evidence (whether for the formation or the evaluation of policies) it enables the necessary international and global collective action against the pandemic. In turn, the necessary conditions that enable such sharing are globally integrated SPI mechanisms such as:

- intergovernmental agencies (e.g. WHO) convening experts and facilitative dialogue;
- multi-lateral research consortia;
- multi-lateral 'war-chest' type funding; and
- opportunities for high-level policy dialogue that includes public policy and science policy, so that countries can better align their science and technology systems.[3]

At the multilateral level, the foremost organisation for establishing discourse and agenda-setting on SPI is the International Science Council (ISC), for which the Program of Work usefully includes the mapping and development of SPIs within the UN system.[4]

Recommendations

The 2019 Global Sustainable Development Report may have issued advice for pre-pandemic world, but its recommendations for Science-Policy-(and society) interfaces not only hold true, but take on added importance in light of the pandemic's lessons. Some of the key recommendations are recalled and reframed below:

- Knowledge sharing platforms with data interoperability and accessibility;
- Permanent national expert panels in key areas of sustainable development;
- Science-Society collaboration and co-design mechanisms;
- Investment in sustainability science which brings together scientific, practical and indigenous worldviews;
- Investment in quality science journalism;
- Investment in science diplomacy to encourage global research cooperation, especially South-South and South-North relationships.

These recommendations can be enacted at both national and multi-lateral (global) levels by a mix of issue-specific and generalized SPI structures and processes. The complexity of these interacting sociotechnical and socio-political impacts of the pandemic have thrown into deep relief the importance of well-structured, well-integrated and well-connected SPIs.

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[1] https://covidandsociety.com/

[2] See the Oxford Super-Tracker: https://supertracker.spi.ox.ac.uk/

[3] See International Science Council and International Institute for Advanced Systems Analysis joint project: Pathways to a Post-Covid world https://stories.council.science/iiasa-isc/

[4] See ISC projects: https://council.science/actionplan/science-creating-solutions/domain-three-science-in-policy-and-public-discourse/ and https://council.science/actionplan/3-1-science-policy-interfaces-at-the-global-level/

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COVID-19 exposes the Gender Digital Divide

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Abstract

The Covid-19 pandemic caused work, education, and many aspects of human life to move into the digital sphere. This sudden move exposed the digital divide and vast discrepancies in access to quality internet, devices, and skills. We analyze data on a range of IT skills that enable workers and students to migrate their activities online. We find that women are systematically disadvantaged in a wide range of IT skills from sending an email with attachment, to making a presentation or coding. The more advanced the skill, the greater the gender gap. As the world moves on from the Covid-19 crisis, it is important to learn from this experience. Equitable access to internet access and skills, prioritizing girls, and women, is imperative for an inclusive digital transformation.

Innovations in the digital economy have the potential to lift living standards of large numbers of people. However, access to innovations are not always shared equitably. In fact, there are many cases of groups of people, even groups of countries being left behind.[1] For example, there was rapid development of the vaccine for Covid-19 but it is primarily rich countries that have been able to access it and widely inoculate their populations[2].

The Covid-19 pandemic and the economic fallout from it have caused setbacks in terms of human development and the achievement of the SDGs[3]. At the peak of the crisis, roughly 1.5 billion children were out of school[4] and across countries, female labor force participation has fallen (Figure 5). At the same time, the impacts of the Covid-19 pandemic have not been even. The impacts on human lives are mediated by existing inequalities in human capabilities. Those with higher levels of education and training have been able to socially distance and conduct their work and lives digitally. This has not been an option for others.

It has been observed empirically, in the past few decades, that while there is convergence in terms of *basic* capabilities, there is divergence in terms of *enhanced* capabilities.[5] While there is convergence in technologies such as mobile phone subscriptions, digital gaps between countries and within countries have been widening when it comes to technologies such as access to computers, internet and broadband[6]. While women and men have equality in the right to vote, women are starkly underrepresented in political bodies and other positions of power, and these gaps are not closing[7]. Gaps such as these came to define the impacts from Covid-19.

As Covid-19 infections spiked, in many countries people were asked to work from home while school systems and universities moved classes online. However, unequal digital capabilities meant that this was not an option in many countries. Within countries too, the success of online work and school depended on the availability of an internet capable device and of high-quality internet[8]. Women face different barriers to access technology than men and were less able to adapt to the switch to online work and services.

This policy brief takes a closer look at the technology divide across gender. It analyses how girls and women perform on a range of technological capabilities, ranging from the basic (copying or moving a file or folder) to the more advanced (writing a computer program), as

[1] For a model where which shows that new technology, while expanding the possibilities for the world, can leave vast sections of the population marooned and without bargaining power see Basu, Caspi and Hockett 2019. On the divide across nations, see United Nations 2020.

[2] See United Nations 2021. Also see Institute of New Economic Thinking (INET) Commission on Global Economic Transformation 2021.

[3] An estimated 119 to 124 million have been estimated to be pushed into poverty as a result of Covid-19. Lakner and others 2021.

[4] Strauss 2020.

[5] UNDP (United Nations Development Programme) 2019.

[6] UNDP (United Nations Development Programme) 2019.

[7] Nayyar and Rivera-Vázquez 2020.

[8] Adjusting the percentage of primary school children facing closures to account for whether the household had access to internet, the estimated effective out-of-school rate presents a lower bound of the out-of-school rate. In 2020, the effective out-of-school rate jumped everywhere. While in low human development countries, it increased by 59 percentage points, to 86 percent, it increased by 41 percentage points, to 47 percent in high human development countries. UNDP 2020.

compared with men. The Covid-19 pandemic and the rapid ramp up of the use of internet technology shows us why this is an important exercise. In the world that we are living in, technological capabilities, who has them, and at what level, can determine who gets left behind.

We find that women are disadvantaged in Information and Communication Technology (ICT) skills across a broad range of skills. On average, the more advanced the ICT skill, the greater the gap in its mastery between women and men. However, there is much regional variance. Based on the findings on access and ability, the brief concludes with some policy recommendations.

Findings

With Covid-19 infections spreading and social distancing becoming the new norm, the sudden shift to remote work and remote learning has exposed existing gaps - only 46 percent of households globally have access to a computer while 60 percent have access to internet at home. When we consider internet users by sex, on average 72.5 percent of men and 69.3 percent of women are using the internet. While the global gender gap is 3.2 percentage points, there are regions such as Central Asia, Southern Asia, and Sub-Sharan Africa where it is greater than 7 percentage points, doubling the digital divide between men and women[9].

Girls and women face underlying, structural inequalities Even in households with access to an internet connected device, girls and women may lack access to these capabilities due to social norms of discrimination. There is evidence of social conditioning whereby even at age five, girls and boys show differences in the kinds of professional roles that they aspire to[10]. Girls and young women disproportionately encounter cyberviolence that manifests itself through threats of physical or sexual violence or harassment, among other forms. The high risk for online violence creates a hostile environment, in which many women self-censor or are driven offline entirely out of fears for their safety[11].

One of the main strategic objectives of the Beijing Platform for Action is for women and girls to have more access to training in technology, yet progress has been mixed[12]. To be able to migrate to online work, working women must be fluent in technical skills. Similarly, in education, to take advantage of online learning, students are required to be digitally literate, and be able to use technology effectively. There are ongoing efforts to identify and address differences across gender in the quantity and quality of engagement with, and learning outcomes from, distance learning opportunities during school closure[13].

Here, we report on data available for 88 countries by gender, from the International Telecommunications Union (ITU) on some of these skills, including copying and pasting within a document, transferring files, using basic arithmetic formulas in a spreadsheet, the connection and installing of electronic devices, creating presentations, downloading and configuring new software and others. These skills range from the basic to more advanced, reflecting the distinction between basic and enhanced capabilities.

Girls' and women's acquisition of skills varies by geographical region (Figure 1). Europe and Northern America and Northern Africa and Western Asia have the highest percentages of women with ICT skills (basic and enhanced), while Sub-Saharan Africa, Central Asia and Southern Asia and Latin America and the Caribbean have the lowest. When it comes to the skill of having written a computer program using a specialized programming language (in the last three months), the rate is quite low in all regions[14].

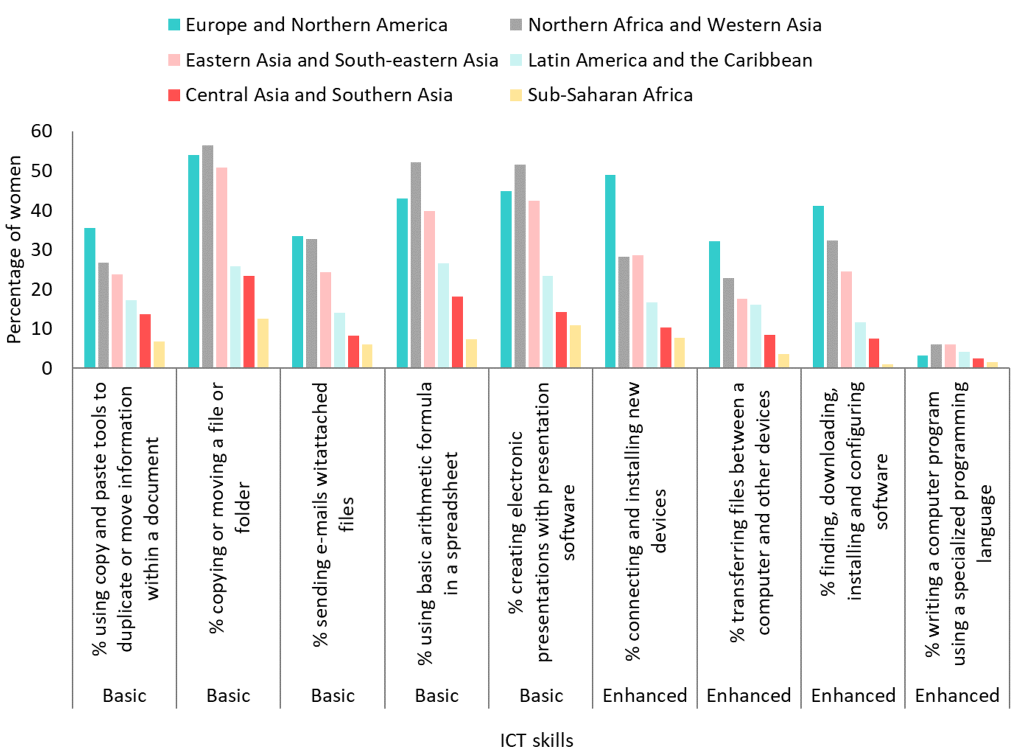
When we look at the gender gap, across every digital skill and every region, women have mastered the skill at lower levels than men – the gap is always positive. On average, we see a trend – the more advanced the skill, the greater the gender gap (Figure 2). The biggest gaps between men and women are in finding, downloading, installing, and configuring software with 6.1 percentage points difference, and in transferring files between a computer and other devices where there is 5 percentage points of difference between men and women.

[9] ITU (International Telecommunication Union) 2021.
[10] OECD 2020.
[11] Lopez 2018. These biases and experiences tend to translate into real lifetime outcomes. For example, only 22 percent of AI professionals globally are women and less than 30 percent of researchers are women (UNESCO (United Nations Educational Scientific and Cultural Organization) 2021.). See WEF (World Economic Forum) 2018.
[12] UNESCO (United Nations Educational Scientific and Cultural Organization) 2020a.
[13] UNESCO Global Education Coalition 2020.
[14] This is low also for men. Overall, in only 11 countries do more than 10 percent of people report having written a computer program using a specialized programming language, in the last three months.

The pattern also holds in the regions Europe and North America and Latin America and the Caribbean (Figure 3). Gender gaps are wider for the more advanced ICT skills. In Europe and North America, the biggest gap between men and women is in downloading, installing, and configuring software with a gap of 10.1 percentage points. In the region Latin America and the Caribbean, the biggest gender gap is in connecting and installing new devices, with a gap of 2.7 percentage points. These gaps are reflected later when women join the labor market. According to the 2018 Women in Tech Index, the percentage of women working in the ICT sector are 14.2 percent in Mexico and 15.5 percent in Chile.[15]

In Sub Saharan Africa and Central and Southern Asia, the regions where women have ICT skills at the lowest levels, the gender gaps are higher in basic ICT skills (Figure 4). In these regions, both men and women have limited knowledge in enhanced ICT skills. The share of graduates in science, technology, engineering, and mathematics programmes at tertiary level that are female is lower than 10 percent in countries like Bangladesh, Angola, Congo, Ghana, Mozambique or Namibia.[16] As there is improvement in the uptake of these skills, it is important to ensure that girls and women, and not just men and boys, have opportunities for learning them.

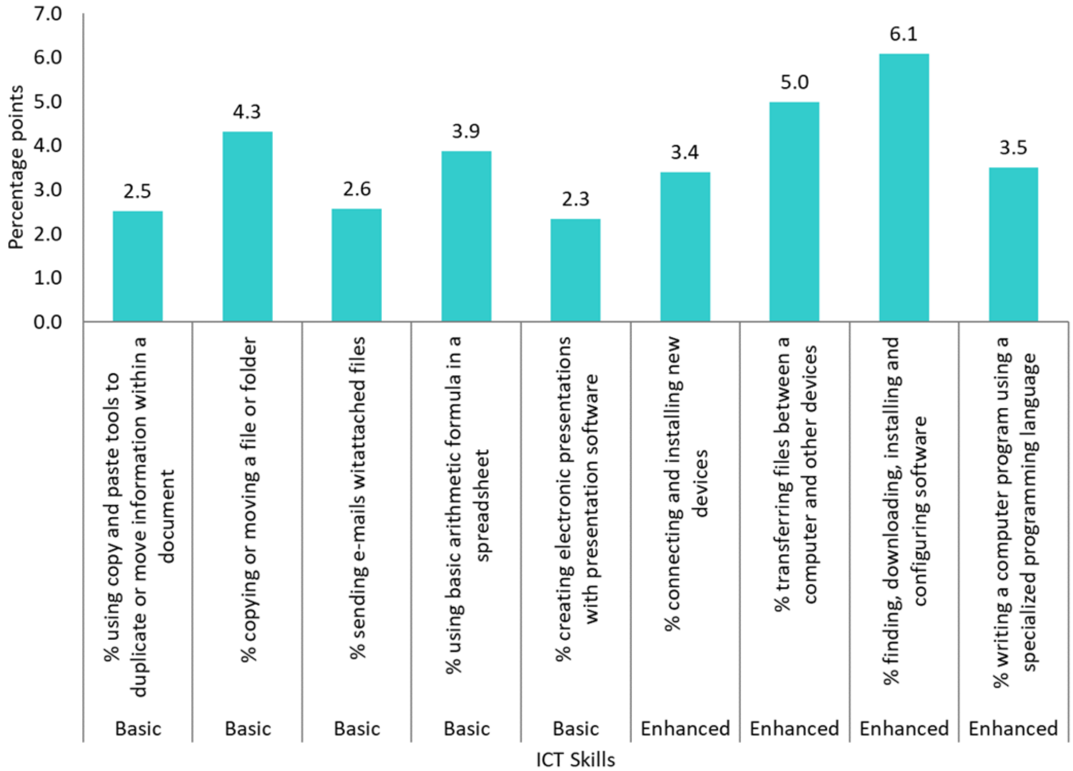
Figure 1. Proportion of young girls and women with information and communications technology (ICT) skills by type of skill and region, last available year.



Data source: International Telecommunication Union (ITU).

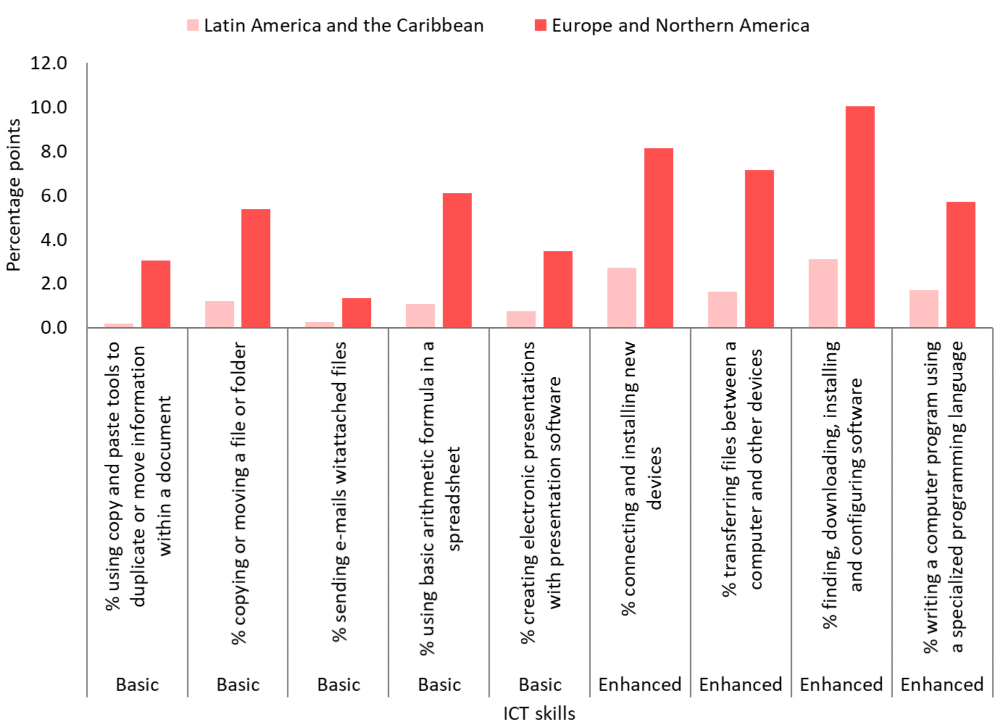
[15] Honeypot 2018.
[16] UNESCO (United Nations Educational Scientific and Cultural Organization) 2020b.

Figure 2. Global information and communications technology (ICT) skills gap between men and women by type of skill, last available year



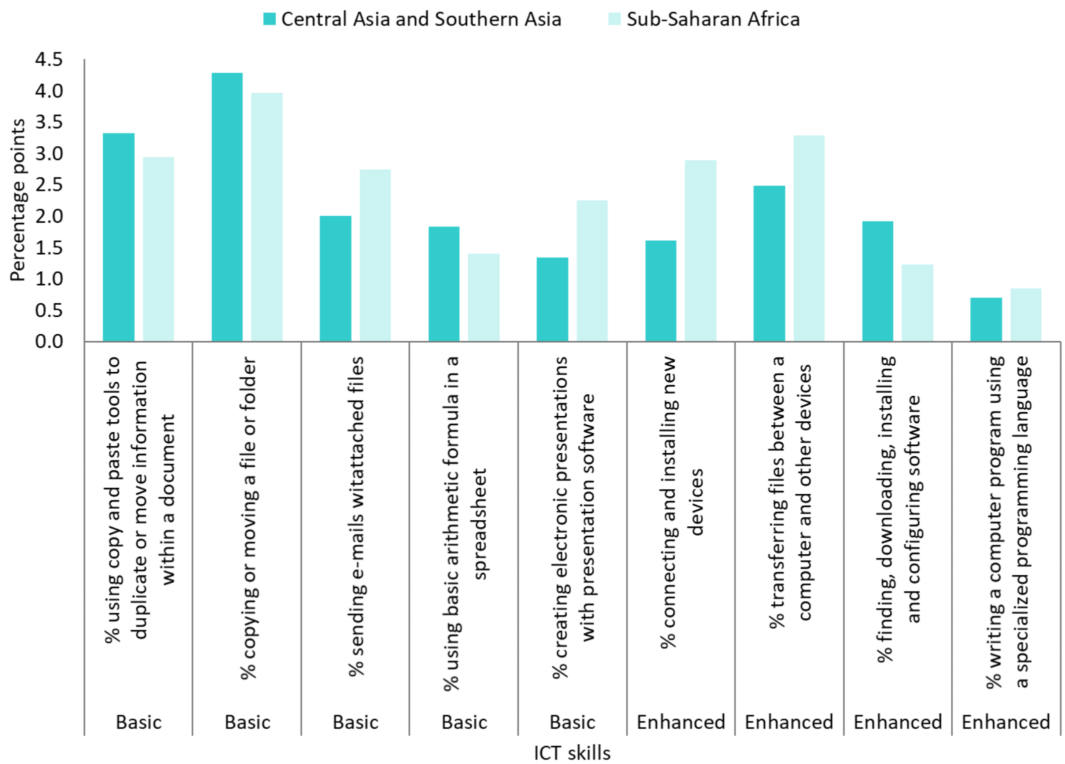
Data source: International Telecommunication Union (ITU).

Figure 3. Information and communications technology (ICT) skills gap between men and women for Europe and North America and Latin America and the Caribbean by type of skill, last available year



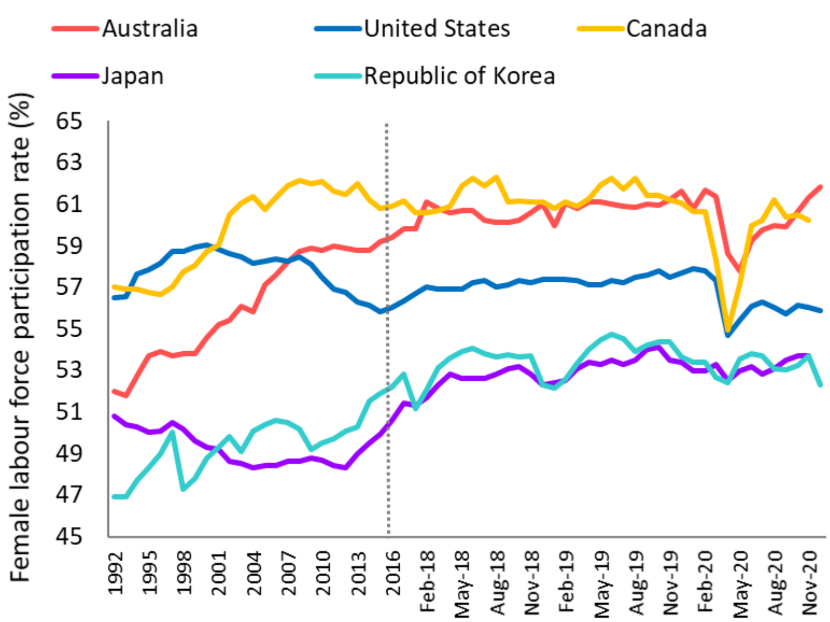
Data source: International Telecommunication Union (ITU).

Figure 4. Information and communications technology (ICT) skills gap between men and women for Central Asia and Southern Asia and Sub-Saharan Africa by type of skill, last available year



Data source: International Telecommunication Union (ITU).

Figure 5. Impact of the Covid-19 pandemic on female labor force participation rate



Note: Refers to the population ages 15 and older.
Data source: Yearly data for 1992–2017 and monthly data from 2018-2020 from ILOSTAT database.

Given the gender digital divide, has the lower women's lower access to digital skills resulted in disadvantages when it comes to Covid-19 related switch to online education, work, and services? The data are still coming in and at present, with available data, it is not possible to establish a causal connection such as this. However, we do see sharp drops in female participation, and this is seen in different countries across the globe. The Covid-19 pandemic pushed 11 million girls out of school while the female labor force participation rate has fallen between 1 and 3 percentage points for countries such as Australia, United States, Canada, Japan and Korea (Figure 5) and 10 percentage points in Mexico, Chile and Colombia[1]. It is important to note that the fall in female labor force participation could also be attributed to other factors such as increased care responsibilities, including of children doing online school and for the elderly[2].

Women also face higher risk of losing their jobs due to automation. It has been estimated that women's jobs have a 70 percent or higher probability of automation, which translates globally to 180 million women's jobs. Women with educational attainment at the high school level have higher risks compared to women that hold a bachelor's degree. In Japan, Israel, the Republic of Korea, and Chile women's jobs are more vulnerable to automation than men. [3]

Conclusion and policy recommendations

As Covid-19 crisis has exposed a range of inequalities[4] and revealed how lack of access to IT skills can snowball into losses in learning, loss in jobs and livelihood, and in being left behind[5]. To counter the impacts on livelihoods and jobs, some countries have put into place policies. Other organizations such as nonprofits have also stepped up. A start-up, Zimba Women, in Uganda has launched an e-commerce platform ZIMBA MART that offers women e-solutions to transition their businesses to online commerce[6]. Some countries have put in place policies that secured digital access for women. In Costa Rica, the Instituto Nacional de las Mujeres (INAMU) launched virtual learning platforms offering distance learning courses for women leaders and expanded the coverage of the *Hogares Conectados* program, as a mechanism to address the COVID-19 crisis and reduce the digital divide. The program provides a computer and internet connection to socioeconomically vulnerable households and 85% of beneficiary households are headed by women[7].

Many of the shifts towards online activity and services adopted during the current crisis are likely to be mainstreamed[8]. The current crisis has speeded up the transition to digital activities. As societies build back better after the Covid-19 pandemic, it is important to ensure that gender gaps in access to digital skills are closed. Beyond the pandemic, policies need to be directed to specifically address access to high quality internet capable devices by girls and women, providing a safe and encouraging environment. In Finland, for example, broadband internet access has been defined as a legal right for every citizen [9]. Awareness campaigns, nudges, and incentives can be directed to change social norms around girls' access to technology and digital learning.

As we have shown, larger gaps are emerging in more advanced digital skills. Training and resources should be targeted more directly at programming and other advanced skills. There are organizations that work directly with girls, helping them acquire skills in programming and machine learning, to solve problems in local communities such as Technovation, Teensinai and Laboratoria and Niñas STEM in Latin America[10]. Governments should partner more extensively with these organizations and scale up their successes. Girls

[1] UNDP (United Nations Development Programme) 2020b.
[2] Azcona and others 2020.
[3] Brussevich and others 2018; Dabla-Norris and Kochhar 2018; UNDP (United Nations Development Programme) 2020a.
[4] See also United Nationa Conference on Trade and Development (UNCTAD) 2020.
[5] See United Nations Conference on Trade and Development (UNCTAD) 2021.
[6] Nefesh-Clarke and Orser 2020.
[7] UNDP (United Nations Development Programme) 2021.
[8] Companies such as General Motors and Facebook have announced that they will permit large fractions of their workforce to continue to work remotely. In other countries, including developing countries, the pandemic is far from over while vaccination proceeds slowly. Online work, school etc are likely to continue. See Kosik 2021; Duffy 2021.
[9] Brussevich and others 2018.
[10] Technovation is a global tech nonprofit organization that has helped 140,000 young people especially girls acquire programming and IT skills to date. Girls work in teams, find a problem in their community, and design a mobile app to address it. Other examples include the Girls in AI initiative from Teensinai. See Technovation; Teensinai.

solving community problems will also help change societal beliefs and expectations about their abilities[11].

Post Covid-19, we are likely to live in an even more digitalized world. Disadvantages in digital literacy, skills and access will matter even more with risks of leaving large swathes of people behind. As the world emerges from the Covid-19 crisis, it is important to prioritize girls and women ICT skills, for them to engage in digital learning and be able to access opportunities in a changing labor market, resulting in a more equitable and resilient system going forward.

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C. Specific technology applications and case studies

Can Big Data Support Assessment of Policy Effectiveness Amidst Crises?

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Note: The views expressed are those of the authors and do not necessarily reflect those of the United Nations or its senior management.

Key Messages

1. Big data provides decision makers with near real-time information access pertaining to the impact of the crisis, especially in humanitarian relief missions.

2. Nontraditional data sources can support the different phases of crisis management from planning to evaluation through timely monitoring and analysis.

3. Analyzing nontraditional data sources facilitates better granularity as individual burdens are mapped to individual devices and reduces biases due to technology dependence owing to the large databases and diversity of sources.

4. The use of big data is no substitute to traditional sources of information, yet it plays a complementary role with supportive information to enable timely and innovative knowledge not possible otherwise., especially during times of crises (e.g., Satellite Images, Call Detail Records, Social Media sentiments).

Introduction

Policymakers have traditionally relied on official statistics to guide and formulate their decisions. These inputs are associated with certain caveats such as being time-consuming, expensive and infrequently updated. Furthermore, in times of crisis, the information they carry might be obsolete for the governmental decision-making process under pressure. With the advent of the Big Data revolution, heralded by the adoption of Machine Learning, nontraditional data, gathered from various sources, have surfaced as useful tools for policymakers. They can be implemented in the various cycles of the policy making process[1], and have proven to be an invaluable tool in the arsenal of decision makers in times of crisis[2,3,4]. With the ongoing debate regarding whether these sources complement or replace official statistics[5,6], two pilot projects were conducted by ESCWA and partners to examine the usefulness of Big Data sources and related tools in the process cycle of making adequate policies. ESCWA's partners included the Ministry of Telecommunications in Lebanon, DataPop Alliance, the Central Administration of Statistics in Lebanon, the Department of Statistics in Jordan, and the Qatar Computing Research Institute.

Project 1: Syrian refugees and host communities in Lebanon

The first pilot project addressed the potential benefits of exploiting Big Data to capture living conditions of Syrian refugees in Lebanon and their host communities. The work relied mainly on four unconventional data streams to evaluate the usefulness of Big Data in a twofold fashion: (i) can a correlation between these Big Data sources and official statistics be established? and (ii) could timely and relevant indicators be derived from these non-traditional sources which would not be available in official statistics?

Call Detail Records

Mobile Call Detail Records (CDRs) have been highlighted as robust and viable surrogates for socioeconomic indicators in previous research[7,8], as many proxies can be reconstructed from the information present in them[9,10]. After reaching an agreement between the Ministry of Telecommunications and the National Statistics Office in Lebanon, CDRs were collected from the mobile providers in Lebanon for three consecutive months from 2016 until 2019. In addition, one of the providers offers an exclusive bundle for Syrian expatriates, which allows a further segmentation of CDRs to the concerned population under study.

The population distribution was estimated based on the number of calls, and mobility patterns were analyzed following security-related events involving Syrian refugees in Lebanon, which indicated that the aforementioned refugees relocated to nearby areas, rather than migrating to more remote regions. It also highlighted the shift in population density in certain areas, which could also be attributed to some refugees returning home or seeking shelter in different countries. Furthermore, economic proxies were created from phone activities, which pointed out to a similarity in working days across the year, established via parametric and nonparametric statistical tests. Finally, a multivariate linear regression was deployed to confirm a strong linear correlation between these proxies and existing official statistics on the subject.

Twitter

Tweets regarding Syrian refugees and their respective host communities were retrieved from Twitter via web scraping and a sentiment analysis was subsequently conducted on them, despite this social media platform not being as popularly adopted as in other countries. Sentiment analysis is a subbranch of Natural Language Processing, itself a Machine Learning paradigm, where text input is passed to the learner and one of three scores (positive, negative or neutral) is attributed to it[11]. It allows policymakers to obtain a feel of the opinion and perception of the general populace on relevant subjects, as well as the impact of certain policies[12,13]. An increase in negative sentiments was witnessed towards all issues (keywords)-related to Syrian refugees, as well as a decrease in neutral stances, coinciding with several security related incidents in different regions across Lebanon.

GDELT

The Global Database of Events, Language, and Tone (GDELT), a repository of news articles in multiple languages[14,15] was also scanned, and its contents relating to salient topics were subjected to a sentiment analysis as well. Similar findings to the analysis of tweets confirmed an increase in negative opinions towards Syrian refugees, and a decrease in neutral opinions, possibly indicating a polarization of writers towards negative sentiments regarding this matter. Furthermore, a decrease in articles redacted in Arabic and an increase in English articles covering these issues spanning 2016 to 2019 was determined.

Facebook

Facebook registration records were gathered and benchmarked with some official population statistics in surveys conducted during 2019 on Syrian refugees and Lebanese host communities. This indicated that both refugees and host communities share similar high school attainment, which however is not reflected by the economic gap separating them. Furthermore, Facebook Adverts Data, which has served as a proxy for population demographics and migration flows[16], was also studied. It reflected a dominance by male users, which could be attributed to mis-registrations for security purposes, or to social familial factors.

Project 2: COVID-19 response policies in Jordan and Lebanon

The second pilot project aimed at utilizing several nontraditional sources to evaluate the effectiveness of certain response policies to the COVID-19 pandemic in both Jordan and Lebanon. The project also developed a web platform tailored for policymakers in the region to investigate the impact of their implemented policies at the national level.

Twitter

Akin to the first project, Twitter was selected to examine the views of the population towards the COVID-19 pandemic socioeconomic repercussions. A sentiment analysis was performed, and the results confirmed a preoccupation by the population with the current state of the economy, and the need to provide adequate financial support to the population at large.

Google Search Trends

Internet search queries pertaining to relevant keywords can serve as a useful lens for policymakers to observe whether a certain policy is garnering more attention by the population. This can be achieved by monitoring search trends (the Google search engine in this case) for selected topics over a specific period, such as a time window spanning the pandemic and the implementation of select related policies. One important finding for instance is the Tkiyet Um Ali Jordanian solidarity fund, which reached a local sudden peak of 100% on March 29th 2020, which concurs with the date of announcement of related policy in Jordan. Another one consists of a peek in January 2021 in Lebanon in reaction to the governmental Impact web platform, which deals with authorization requests to drive, following the imposition of total lockdown measures for the upcoming two months.

Google search queries have also found applications as an informative exogenous variable in predicting several macroeconomic time series[17,18,19]. This is especially true for nowcasting purposes[20,21], where the current value of an indicator exists but has not yet been released[22]. In this project, this was achieved by adopting the Structural Bayesian Time Series framework[23], which relies on a Kalman filter to model the regular components of a time series[24], the Bayesian Spike and Slab variable selection method to determine which relevant keywords should be retained[25], and Bayesian Model Averaging to mitigate the effects of forecasting model uncertainty[26,27]. This approach yielded a promising performance in nowcasting unemployment rate in Jordan on a holdout set[28], displaying a better forecasting accuracy than other time series models which do not contain the queries.

Mobility Reports

Mobility reports have been publicly released exclusively in times of pandemics by Social Media titans. These however are limited to a certain granularity in the information they display, and their availability is context-dependent. Nonetheless, they allow policymakers to gauge the compliance of the population to mobility restrictions. The results of the mobility mapping from Facebook's Data4Good and Google Mobility reports in all Lebanese districts show that there are important behavioral differences during the quarantine and the recovery phases between poor and more affluent districts.

Nighttime Satellite Imagery

Remote sensing has proven to be a crucial asset in policymaking during crises[29,30]. VIIRS Nighttime satellite images were extracted from Google Earth Engine during the COVID-19 period, and were compared to their counterparts from the previous year. These were first subject to filtering algorithms, as their visibility is hampered by several meteorological and environmental factors[31,32]. Between April 2019 and April 2020, COVID-19 and other local crises

resulted in a night-time light sharp decrease of Beirut area between 30 to 60%, clearly indicating the severe economic impact of the changes.

Policy Recommendations

1. The digital footprint is already present with national public utilities, traffic, and operations of urban settlements. This data asset should be harnessed for mobility analysis to decouple from data dependence on social media platforms that are made available only during the crisis as identified by these commercial enterprises.

2. In cyclic crises like COVID-19, "near real-time" corrections can be suggested, which are an improvement to the blinded decisions made under pressure for totally justified circumstances.

3. Governance of data is critical for an institutional sustainable process to secure future cooperation and partnerships. In addition, trust in data sources and related analysis is essential for building confidence and buyout of recommendations. The equilibrium trade-off state can be achieved while balancing between data richness (accuracy and usefulness) and the protection of privacy (governance). Partnerships and convening of stakeholders become an integral part of any project implementation.

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Ma3an-Together Against Corona, The Official Lebanese Contact Tracing App: Experience and Lessons Learned

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Abstract

National governments around the world are relying on digital tools to speed up and scale up contact tracing of individuals affected by Corona Virus Disease 2019 (COVID-19) to mitigate or contain potential resurgences. Several countries have implemented mobile apps as complementary tools for rapid contact tracing and notification of potentially infected or high-risk individuals. Similarly, Lebanon has developed a COVID-19 contact tracing and exposure notification app called “Ma3an – Together Against Corona”, as part of its mitigation measures to combat the virus. The app aims to complement manual contact tracing activities carried out by the Ministry of Public Health (MoPH). Ma3an was conceived and developed by the MoPH and a team of experts from the interfaculty Humanitarian Engineering Initiative (HEI) at the American University of Beirut (AUB), in collaboration with the developer TedMob.

The name Ma3an, a transliteration of the Arabic word “together”, emphasizes citizens’ sense of shared responsibility and collective effort needed to break transmission chains and reduce viral spread. The app uses low-energy Bluetooth technology to detect nearby phones of other app users. Through the Bluetooth antennas, the phones of Ma3an users who come in close proximity would detect each other’s signals and periodically exchange alphanumeric identifiers or keys that indicate a contact, without collecting nor revealing any personal information from the users. This information is securely stored on the users’ phones and protected by encryption. Once app users test positive, the data on their phones are uploaded to a MoPH server for analysis. App users who are identified as high risk, based on proximity and duration of the contact with an individual who tested positive, are notified via the app without revealing the identity of the positive case.

The Need

Since the beginning of the COVID-19 pandemic, many countries relied on lockdowns as primary non-pharmacological intervention to control the spread of this great public health threat. Until now, lockdowns bore high socioeconomic costs and were ineffective in curbing the pandemic [1]. One potential tool for a successful exit strategy is contact tracing that attempts to identify people exposed to COVID-19 and stop the onward transmission. This can be facilitated and automated by mobile apps. As of March 2021, more than 140 countries and territories in the world established digital contact tracing apps [2]. Recent research has praised mobile apps as an essential tool among the repertoire of interventions to “flatten the curve” of COVID-19 infections [3]. For example, Hinch et al. showed through an epidemic simulation of UK data, that a contact tracing app could help in lifting a lockdown and suppressing the pandemic, if around 60% of the population used it [4].

In Lebanon, the Government has responded with various levels of lockdown to prevent health systems from being overwhelmed. However, since the Beirut Port’s Blast on August 4, 2020, the country has been suffering from an alarming surge of cases that dramatically drained the healthcare system [5]. Lebanon has also introduced several non-pharmacological mitigation interventions, including mandatory physical distancing and mask wearing, which saw varying levels of compliance. Among such interventions, the identification and isolation of positive cases through contact tracing played a substantial role, particularly at the outbreak onset. However, it was evident that manual contact tracing could not work at scale. With limited resources available, there was a critical need to strengthen, intensify, and increase the efficiency of contact tracing efforts of the Epidemiologic Surveillance Unit at the MoPH. In this regard, a mobile app could help trace and alert more contacts as it could trace contacts unknown to a positive case and could notify contacts quicker and with fewer human resources than manual contact tracing. In a true public-private partnership, MoPH, HEI, and TedMob designed and developed “Ma3an –Together Against Corona" (معا ضد الكورونا), the official contact tracing app for Lebanon.

Components of a Digital Contact Tracing App

Developing a digital public health intervention requires going beyond the technology and addressing a multitude of factors as a prerequisite for success. Two primary guidelines were followed in this regard, WHO[56] and Google/Apple[57].

Privacy and Transparency

Arguably the most important factor for a contact tracing app is the trust of the public in the system. This comes about by guaranteeing privacy, anonymity, confidentiality, appropriate data protection, and transparency in data management. Privacy was ensured through technical and data logging design decisions, by utilizing encryption and strict restrictions to data access. Along these lines, only necessary data (signal strength level indicator, random numbers, date, time) needed for tracing was logged for the shortest possible duration (21 days) and retrieved from the phones only when needed (user tested positive). At app installation, only the user's mobile phone number was used to validate the registration, with no other private information required. Anonymity was guaranteed by using random encrypted numbers to log encountered devices instead of actual phone numbers and these numbers were periodically updated (20 min validity). Transparency measures included clear consent at app installation, explicit consent at data upload, and a publicly published privacy policy[58] detailing user rights. In addition, this is one of the rare times where a government-led project publicly posted the source code of the app[59].

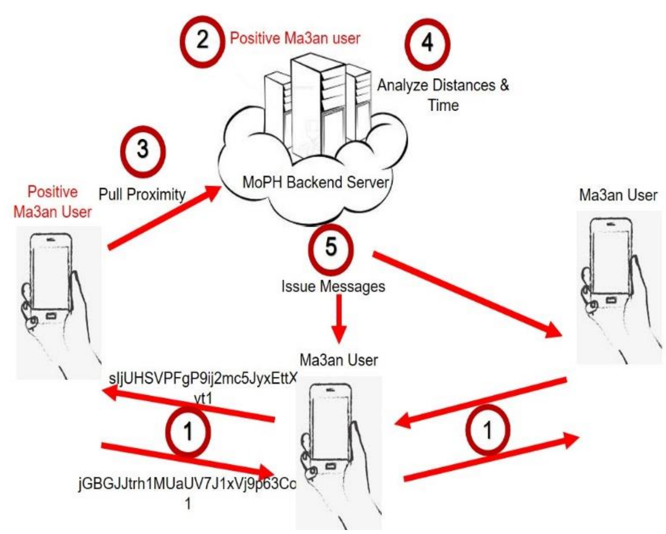
Technical

Ma3an uses Bluetooth technology to broadcast random numbers anonymously to other mobile phones using the app. The apps on each user's phone log these numbers along with the time/date and received signal strength (as a correlate of distance in meters). This data is logged by the phones locally. The MoPH is informed of positive cases by national laboratories in Lebanon daily. The MoPH queries the registration database for phone numbers of positive cases, and only then sends them a notification requesting the tracing data saved on their phone. The time/date and signal strength are inputted into a risk model to identify cases "at risk". These high-risk cases are then notified through Ma3an of their exposure. Fig.1 illustrates this sequence of events.

Using this model, the app design follows a hybrid (decentralized data logging and centralized tracing) approach for data storage in such a way that it stores encrypted data only on the phone, not on a central database. The collection, use, and storage of data is limited to positive cases and only for the purpose of contact tracing. The data is stored on secure servers (encrypted in transition and in storage) and managed only by the MoPH staff with special authorization.

During the development phase, the app went through extensive testing to evaluate its impact on battery life and the correlation of received signal strength with distance. The results validated what is already known in the literature regarding the limited accuracy of deducing distance from received signal strength. These results informed the risk model developed.

Figure 1. Data Flow through Ma3an-app



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56 https://www.who.int/publications/i/item/contact-tracing-in-the-context-of-covid-19
57 https://covid19.apple.com/contacttracing
58 https://www.moph.gov.lb/en/ma3an
59 https://github.com/Lebanese-Ministry-of-Public-Health

Risk Model

The log data downloaded from the phone of an app user with confirmed COVID infection are processed on the MoPH backend server. Data are processed separately for two different time intervals. One interval starts at one-week prior to diagnosis and ends at diagnosis. The other time interval starts three weeks prior to diagnosis and ends one week before diagnosis. During each of these time periods, the total contact time with the diagnosed case is estimated for each app user logged on the phone. The estimation works as follows: only signal strengths that correspond to an approximate distance of 2m or less are considered. When two consecutive log signals of the same user are separated by 10 minutes or less, the time interval between these two signals gets added to this user's total contact time. For each time interval above 10 minutes, 90 seconds get added to the total contact time. The user anonymous IDs and their total contact times within each of the two time periods are returned to the MoPH. Authorized MoPH staff then decide based on the estimated contact times in each time period which user to notify.

Branding, Messaging, and Campaign

The team conceptualized the brand name, which had to include the concepts of "tracing", "togetherness" and the virus, and was based on a systematic and extensive review of contact tracing apps developed globally.

The team also coordinated the development of the content of the app (the screens and messages that the app uses) and developed an integrated marketing and communication strategy, aiming to motivate app downloads and correct use (enabling notifications and Bluetooth). The general target population included any person traveling to Lebanon or residing in Lebanon (being Lebanese or of other nationalities), who spoke English or Arabic, and who owned a phone running on Android or iOS systems, compatible with the app. Two main priority segments were identified: travelers coming from abroad and residents. The latter segment was further divided into youth and those residing in crowded areas. For each target segment, we identified key communication objectives (what users need to know, believe, or do), messages, and tactics, that are activities necessary for reaching the objectives.

Governance

The work of the Ma3an team was guided by the principles of respect, fairness, and reducing suffering from COVID-19, and the ethical principles of autonomy (e.g., voluntariness in using the app), beneficence (e.g., the app serves the community and is for the greater social good), and equity and justice (e.g., the app should be available for all). In the absence of a local legislation specifically addressing data protection using digital information, the Lebanese Law 81 was used as a minimal standard framework to develop the app's privacy policy. All the information related to data protection and human rights is explicitly included in the policy document.

The Ma3an team proposed to establish an independent, expert oversight advisory board, tasked to oversee the effective implementation of data protection guidelines. Currently, the advisory board is being formed.

Assessment

Output indicators that are constantly monitored are: user downloads, user behavior/adherence, number of positive users, and number of contacts traced. The desired outcomes were: compliance of contacts with instructions which could be demonstrated by a reduced transmission/positivity rate among the users of the application; identification of clusters of transmission for quick deployment of mitigation strategies; and risk model correlation to users who test positive to be able to calculate a reproductive rate for Lebanon. However, up to the date of writing this brief, it was not possible to assess outcomes due to the low and slow uptake of the app which the team attributes to the absence of a targeted communications campaign and the lack of adoption of the app as part of the national response strategy. The low contact tracing numbers among app users and the surge in positive cases in the country indicate a less than ideal implementation.

Limitations

Even if using a contact tracing app proves to be effective as part of a public health response in one country, it may not be efficient or applicable in another. The efficacy of digital contact tracing will depend on several social and economic factors. In the Lebanese experience we faced the following challenges:

1. One of the key barriers we experienced is related to public awareness of the application and the importance of contact tracing.
2. The overarching main challenge faced has been funding. Although all entities involved in the design and development carried out the work pro bono, the team faced several rejections from local and international agencies to fund the minimal operational cost needed for the system hosting and to fund a nationwide communication campaign.
3. We are also aware of the inequality inherently introduced by such tools when it comes to

individuals with no phones or those with low digital literacy.

Conclusion and Implications for Policy

We have witnessed tolerable public support for the Ma3an app in tackling COVID-19. Since its initial release on 30 September 2020, the app registered over 75,000 downloads (~ 1% of the population). Since the launch of Ma3an up until 26 March 2021, Lebanon had 412,661 positive cases with 7,530 (1.82%) of those being Ma3an users. This number can improve if funding is available to implement the communication strategy to promote the uptake of the app. Even with vaccines rolling out worldwide, we still need effective and efficient contact tracing to control possible new outbreaks, particularly with new virus variants. However, given that the app would only be successful if downloaded at scale, voluntary download is the main barrier to the effectiveness of contact tracing apps - as evidenced by the comparison between countries that make it mandatory and those who do not [6].

Policy Recommendations:

1- Ma3an has to be integrated into a wider national strategy where digital contact tracing is part of the comprehensive response.

2- A clear financial commitment is required from the government to sustain and scale up this intervention.

3- Mandate Ma3an use to gain access to all closed public spaces such as supermarkets, restaurants, malls, gyms, schools, etc. Public-private partnerships are key to enforce such a regulation; institutions have a vested economic interest in contributing to breaking the chain of transmission as opposed to being forced into repeated lockdowns.

4- Partner with large organizations (syndicates, universities, companies, etc.) to encourage members to download the app.

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Addressing COVID-19 pandemic: Space technology for global health

UN Office for Outer Space Affairs

Note: The views expressed are those of the authors and do not necessarily reflect those of the United Nations or its senior management.

Abstract

In 2020, the world faced an extraordinary situation with global pandemic spreading into every corner of our planet and affecting societies and their health, economy, tourism, sports and culture among many other areas in an unprecedented way. The COVID-19 pandemics demonstrated that innovative approaches to solve health problems were needed to complement traditional good practices in the health sector. Such approaches include the use of space science and technology for health promotion, health protection, surveillance, contact tracing, transmission monitoring, health-care delivery in remote areas using telemedicine and tele-health services. Space science and technology provide innovative research platforms for advancing medical knowledge and spin-offs for the development of health-care equipment, operational activities and procedures. Space-based data and technologies foster connectivity in health emergencies, and the integration of space-derived information in health-care systems supports the mapping of populations, the treatment of diseases, the distribution of medication, transportation systems and water supply and sanitation and facilitates the monitoring of trends in air quality and health-related environmental factors.

OOSA

The Office for Outer Space Affairs builds national capacities through its Space Applications Programme, and has organized capacity-building activities on applications of tele-health to service delivery in public health and environment; space technology contribution to infection surveillance; tele-epidemiology contribution to public health actions in the context of climate change adaptation; use of space technology for improving public health. The Office coordinates space-related activities within the United Nations system and leads UN-Space, an inter-agency cooperation mechanism. The use of space science and technology for global health is addressed in the special report of the Inter-Agency Meeting on Outer Space Activities (A/AC.105/1091). The United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) of the Office facilitates the use of space-based technologies for disaster management and emergency response and disseminates, through the dedicated UN-SPIDER knowledge portal, examples of experiences and practices in using space for addressing COVID-19. The Office, in its capacity as secretariat of the Committee on the Peaceful Uses of Outer Space, supports international cooperation in the use of space science, technology and information for global health among Member States through substantive support to the work of the Working Group on Space and Global Health of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space.

Outline of policy issues

Microgravity for the development of vaccines and medication

Since the first human space flight in 1961, opportunities to conduct science experiments stretched beyond the Earth's surface and atmosphere. The International Space Station, the largest, most complex and most long-standing international cooperation endeavour in outer space to date, has carried out research, technological development and testing, operational activities, medical procedures and other health-related projects. The unique condition at the space station allows not only to examine the adverse effects of the microgravity environment on the human body, such as balance disorders, cardiovascular deconditioning, bone demineralization and muscle disuse atrophy, but also use the microgravity environment for the development of vaccines and medicines.

Microgravity allows protein molecules to get aligned in an orderly manner, creating a high-quality crystal that enables the structural analysis of medically important proteins and enhances the understanding of biological structure-function relationships. As such, protein crystallization experiments were performed on an enzyme of a malaria parasite, to gain understanding of potential treatment of malaria. Furthermore, the microgravity environment may resemble human intra-intestinal conditions, both having a similar level of fluid shear, a so-called mechanical force related to the motion of fluids passing over cells, which allowed studies of various zoonotic agents with the view to develop new therapies and vaccines to combat salmonella infections in humans.

With general public getting increasingly familiar with such terms as messenger RNA (mRNA) flooding the news covering the race for COVID-19 vaccines, little awareness exists of microgravity's potential in screening molecules that could aid in the identification of healthy and nonhealthy cells and potentially lead to treatments for cancer, COVID-19 and beyond. The first COVID19 drug research in space started operations in December 2020 in the European commercial ICEcubes facility on the International Space Station, aiming at increasing understanding how a broad-spectrum antiviral medication remdesivir interacts with its delivery substance cyclodextrin so that the drug's efficiency can be improved.

Contribution of space industry to responding to COVID-19

Technology development and testing on or for space activities often produce incidental benefits or pay-offs for everyday technology in health care on Earth. The directly applicable or spin-off/spin-in/spin-through technologies led to advances in new materials, devices, procedures and organizational systems used in health care. Materials initially developed for space flights can be found in daily life in lightweight wheelchairs, scratch-resistant lenses, invisible braces or first aid thermal blankets. Magnetic resonance imaging (MRI), computed tomography and infrared ear thermometers are examples of spin-off devices. Recognizing the shortage of respirators needed to assist patients with COVID-19 respiratory symptoms like coughing, trouble breathing, and shortness of breath, NASA announced the development of Ventilator Intervention Technology Accessible Locally (VITAL), a ventilator prototype designed specifically to address the COVID-19 pandemic

Isolation and confinement lessons from human spaceflights

The COVID-19 pandemic has led to implementation of social distancing and lockdown strategies, aiming at slowing down the spread of the COVID-19 pandemic, but also resulting in psychological and physiological challenges associated with prolonged isolation and confinement. For decades, space research looked at the need to study the effects of social isolation on mental well-being and performance. Isolation experiments lasted for 60, 110, 135 and 240 days, culminating in the longest physical isolation experiment in history, namely, the Mars-500 mission conducted by Russia's Institute of Biomedical Problems (IBMP), with extensive participation by ESA.

During the Mars-500 mission, three different crews of volunteers lived and worked in a mock-up spacecraft in Moscow. The final stage of the experiment, which was intended to simulate a 520-day crewed mission, was conducted by an all-male crew consisting of six international crew members. The mock-up facility simulated an Earth-Mars shuttle spacecraft, an ascent-descent craft, and the Martian surface. The volunteers who participated in the three stages included professionals with experience in engineering, medicine, biology, and human spaceflight. The experiment yielded important data on the physiological, social and psychological effects of long-term isolation, and could provide insights to better coping strategies and psychological support during the COVID-19 pandemics.

Satellite communications for addressing social isolation and tele-education

Space technology through satellite communications offer tools for tackling social isolation and loneliness at the time of the pandemic and allows for contactless social connection and networking. Satellite-based internet facilitates social connectivity, reducing loneliness resulting from social distancing and lockdowns during the COVID-19 crisis. Furthermore, communication technologies have been the core enabler for tele-educaton, allowing educational systems to adapt and develop new ways of learning, as well as identify solutions to mobilize learners remotely.

Space Technology for Health Situational Awareness

The role of Global Navigation Satellite Systems (GNSS) in the current COVID-19 pandemic is also substantial, ranging from contact tracing to locating the positively tested, leading to identifying risky locations, helping in the adoption of policies by understanding mobility, and monitoring the environmental factors of the lockdown measures and spread of the disease. Beyond individuals, a combination of navigation and communication technologies is instrumental in monitoring and detecting changes in traffic of cars, trucks, vessels and trains. Monitoring of congestion levels at parking lots, roads, and other transport-related facilities became an useful tool in indicating early disease activity.

Tele-epidemiology

Tele-epidemiology combines the use of information from satellite-based platforms to investigate and forecast outbreaks and the re-emergence of infectious diseases. The use of remote sensing has significantly advanced the possibility to track and visualize the real-time evolution of local outbreaks and epidemics and map the environmental influences for the epidemics and critical public health infrastructure. Space-derived information is used in tele-epidemiology in programmes for specific diseases, such as yellow fever, cholera and leptospirosis, to develop a decision-support tool and to provide information for current vaccination strategies.

Telemedicine

Telemedicine is an integral part of medical care on the International Space Station. Medical teams of doctors, psychologists and imaging specialists keep close contact with crews on missions and guide them through health issues. Preventive, diagnostic, and therapeutic care, as well as urgent care in space is provided through the use of telemedicine. The COVID-19 pandemic reconfirmed the importance and usefulness of telemedicine as a means to connect patients and health professionals when a consultation in person is not possible. The use of telemedicine eliminates direct physical contact and minimizes the risk of COVID-19 transmission, enabling to ensure the continuity of availability of medical care.

Policy recommendations

The following recommendations could be considered, including in relation to COVID-19:

(a) Raising awareness of the potential contribution of space technology and applications to global health;
(b) Engaging with users, researchers, decision makers and other stakeholders in the public health sector to identify further needs in tools and data that could be provided with the means of space technology and its applications;
(c) Strengthening capacities in terms of the discovery of, access to and processing and use of space-derived data and information and furthering the development of relevant tools and information systems;
(d) Promoting institutional development by focusing on advancing the integration of space-derived data and information into the decision-making processes in public health;
(e) Supporting the harmonized use of space technology in public health through the standardization and updating of space-derived information, with a view to eliminating duplication and overlap;
(f) Promoting international cooperation for increased use of space-derived data and information for planning and decision-making processes in public health, including for the mitigation of impacts of humanitarian crises.

D. Country experiences, updates on activities and news

Mobilizing Science, Technology and Innovation for the Post-COVID Era in Japan and beyond

MORIMOTO Koichi, HARAYAMA Yuko, and NAGAI Ryozo, Engineering Academy of Japan (EAJ)

Acknowledgment: This policy brief is a summary of the result of discussions at the Committee on Post-COVID-19 Era, Engineering Academy of Japan (EAJ). We thank the members of the Committee on Post-COVID-19 Era for their active participation, as well as the experts who made presentations at the Committee for their valuable contributions.

Humans and Infectious Diseases

The relationship between Humans and infectious diseases has a long history. Infectious diseases have claimed many lives throughout eras, such as the plague in medieval Europe and the Spanish flu pandemic of 1918. On the other hand, means of preventing and treating infectious diseases advanced dramatically from the 18th century onward due to the development of vaccines and the discovery of antibiotics. In 1980, the World Health Organization (WHO) declared smallpox eradicated, which had the consequence of removing infectious disease control from the policy priority list. However, infectious diseases have, in fact, subsequently evolved into an even greater threat, exemplified by the emergence of acquired immunodeficiency syndrome (AIDS), and the global spread of diseases such as severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), and new influenza strains.

The outbreak of the new coronavirus disease (COVID-19) has hit our economic and social systems, sounding a warning to the comfortable daily lives we have thus far taken for granted, and forcing us to rethink our values. The relationship between policymaking and science has had a significant impact on developments during the pandemic, as humanity has striven to find optimal solutions that balance the sometimes conflicting demands of preventing the spread of infection while maintaining economic and social activity.

As most infectious diseases are caused by pathogens that are transmitted to humans through wild animals or livestock, the concept of zoonosis has become a foundation of infectious disease theory. In addition, the concept of One Health has been advocated in recent years. This approach takes a holistic view of human health, arguing that humans are but one component of the global ecosystem and that conservation of the ecosystem can only be achieved when both humans and animals are healthy.

The Status of COVID-19 in Japan

Japan has thus far experienced infection peaks in three separate waves, with the government twice declaring a State of Emergency, in April 2020 and January 2021. From the outset, the Japanese government has asked citizens to avoid "closed spaces with poor ventilation," "crowded places with many people nearby," and "close-contact settings such as close-range conversations," and has urged a change in behavior at the individual level, including encouraging people to wear face masks and wash or sanitize their hands. The government has also called for public cooperation in promoting teleworking, refraining from non-urgent outings, and requesting bars and restaurants to shorten their opening hours. However, with an increasing number of infected patients putting a strain on the ability of medical institutions to accommodate them, in February this year the law was revised to further enhance the effectiveness of infection prevention measures and to stipulate the support provided to businesses and local authorities.

It is stipulated that when declaring or lifting a State of Emergency, the government will make a comprehensive judgement based on monitoring of objective indicators related to the status of infected persons and medical institutions. In doing so, it is essential to consult the views of experts with advanced knowledge and to ensure close communication with the heads of local governments.

Shifting to a Data-driven Society

When making decisions that will impact society as a whole, the advanced use of information and communication technology (ICT) is extremely effective in refining decision-making based on data, accurately assessing the impact of behavioral changes, and utilizing big data. In particular, in the efforts to prevent the spread of infection, the deployment of data analytics would enable us to detect the infection spread in advance and to better understand the characteristics and propagation mechanisms of viruses whose properties are yet unknown.

For example, numerical simulations of viral spread conducted by RIKEN[1] using the *Fugaku* supercomputer have enabled researchers to visualize how differences in building shape, seating arrangements, wearing of masks and protective equipment, and ventilation methods play a role in the spreading of viruses. Visualizing the dispersal and spread of the virus helps control the spread of infection by allowing citizens and governments to obtain a better understanding of behavioral patterns which can reduce the infection rate.

On the other hand, from a bioethics perspective the vast amount of data accumulated by medical institutions and local governments requires special treatment as personal information when handling. In order to consolidate data on infection status and genome analysis from across Japan in a consistent manner, and to promote broad-ranging application of this data while at the same time taking due care to protect personal information, there are a number of issues that must be resolved. In addition, when making future predictions regarding infection spread, calculation results may differ significantly depending on the model used and the way various parameters which form the basis of the calculation. When promoting the use of data science to design society, the choice of a scenario among the range of available ones, will ultimately rely on a consensus considering multiple social factors.

Testing and Diagnosis

The first step that must be taken when establishing countermeasures against infectious diseases is to identify infected persons and the spread of infection. Polymerase chain reaction (PCR) testing is considered the most effective way of identifying COVID-19 infection in individuals, and large-scale PCR testing is generally regarded as essential in order to control the spread of infection.

PCR testing in Japan has focused on controlling infection clusters, through regional public health centres working to control the spread of infection by concentrating on tracing the infection route and identifying close contacts. However, as community transmission increased, primarily in urban areas, this basic policy was revised in March this year to expand the scope of PCR testing to include unspecified asymptomatic people in order to detect signs of a resurgence in the infection spread as quickly as possible.

Meanwhile, a number of mutated strains of the novel coronavirus are beginning to spread across a wide range of regions. With some of these mutant strains confirmed to be highly infectious, in addition to implementing thorough border measures such as airport testing and quarantine for those entering the country, it is important to expand systems for analyzing the entire viral genome in order to accurately identify community transmission, and to develop test methods for rapidly detecting mutant strains.

Vaccination

It goes without saying that the development and rollout of vaccines is critical in order to prevent the spread of COVID-19. Although there is a pressing need to expedite the vaccine development and approval process, any vaccine deployed must also be extremely safe, as these will be administered not only to healthy individuals free of infections but also to those with underlying conditions.

While supporting the research and development of domestically produced vaccines, Japan has also concluded contracts or basic agreements for vaccine supply with three pharmaceutical companies abroad. The first vaccine was submitted for approval in December last year and approved in February this year. The rollout of the vaccine has started with healthcare workers, with vaccination of the elderly scheduled to begin in April. Vaccines from the remaining two companies were respectively submitted for approval in February and March this year.

When deploying vaccines, thorough, evidence-based communication is essential in order to allay the public's concerns regarding their safety and effectiveness. In particular, addressing the public's doubts and concerns regarding viral mutations and individual differences in immune function will help instill a sense of security and promote societal acceptance of the accomplishments of cutting-edge science and technology.

International Cooperation

Controlling infectious diseases requires the collective wisdom of the global community, and Japanese researchers and other collaborators are utilizing international networks to help generate global commons. The output from these collaborative efforts has been used to provide scientific advice to policymakers and other stakeholder in a range of countries via forums such as the Global Research

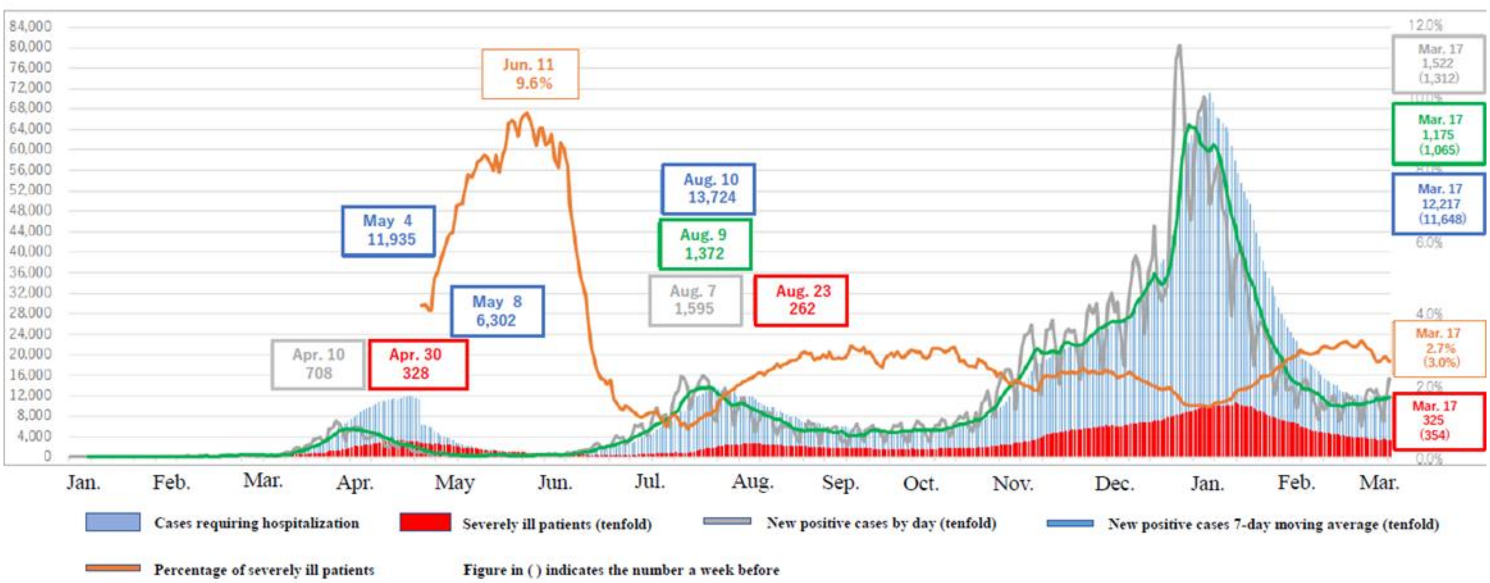
Collaboration for Infectious Disease Preparedness (GloPID-R)[2], and the World Health Organization (WHO) R&D Blueprint[3] for action to prevent epidemics. Furthermore, the Coalition for Epidemic Preparedness Innovation (CEPI)[4] was launched as a public-private partnership at the World Economic Forum in Davos in 2017 with the aim of establishing a mechanism (World RePORT)[5] for sharing data from research and development findings to allow rapid action to be taken on a global scale.

GAVI, the Vaccine Alliance, has launched COVAX Facility: COVID-19 Vaccine Global Access Facility[6] to distribute vaccines broadly with the aim of reducing disparities between countries and regions. Around 190 countries have announced their participation in the scheme. By the end of 2021, the program aims not only to provide two billion doses of safe and effective COVID-19 vaccines that have been approved by regulatory authorities or pre-approved by WHO, but also to achieve equitable vaccine distribution regardless of income level among vulnerable populations, which comprise 20% of participant countries. Japan is also leading the formation of this framework and has announced a 200 million US dollar contribution.

Challenges and Future Outlook

Circumstances surrounding the spread of COVID-19 are closely related to a range of political, social, and cultural factors, each of which will have a significant impact on future developments. If we can rapidly implement comprehensive measures to overcome the crisis, while using the opportunity to rethink our fundamental systems, new prospects for the future will emerge. In particular, we need to attach much value to the establishment of trusting relationship among the policymakers and scientists, as well as human resource development. If we are to turn this global crisis into a leap forward to a new tomorrow, cross-border collaboration and a strong will to challenge the unknown will be of paramount importance. It is essential our current experience is passed on to future generations as valuable lessons and used to develop economic and social systems that are capable of learning and evolving.

Figure. Evolution of COVID-19 in Japan (Jan. 2020 - Mar. 2021)



Source: Novel Coronavirus Response Headquarters： March 18, 2021

Notes:

*1 Domestic cases excluding those returning from overseas on charter flights. From May 8, 2020, the data source was changed from figures collated from individual data obtained by the Ministry of Health, Labour and Welfare, to figures collated from data published by local governments on their websites.

*2 The ratio of severely ill patients is calculated from May 8, 2020, when the collation method was changed. The ratio of severely ill patients is defined as the percentage of severely ill patients among cases requiring hospitalization, etc.

*3 Care is required when making comparisons as the scale for patients requiring hospitalization, etc. differs from that for severely ill patients and new positive cases (the number of new positive cases and severely ill patients has been magnified tenfold).

*4 In some prefectures, the number of severely ill patients is calculated using published figures that have been collated according to the prefecture's independent standards, and does not include patients who need to be managed in intensive care units (ICUs), etc.

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The Philippines' STI solutions to combat pressing issues and the COVID-19 pandemic

Department of Science and Technology, the Philippines

Abstract

This brief discusses the scientific initiatives and policies implemented by the Philippines to address a wide array of challenges. It features the Philippines' immediate, medium-term, and long-term solutions and policies to respond to the COVID-19 pandemic. It illustrates how a developing country, through the practices of the Philippines, maximizes the application of advanced technologies as investment to elevate the nation's competitiveness.

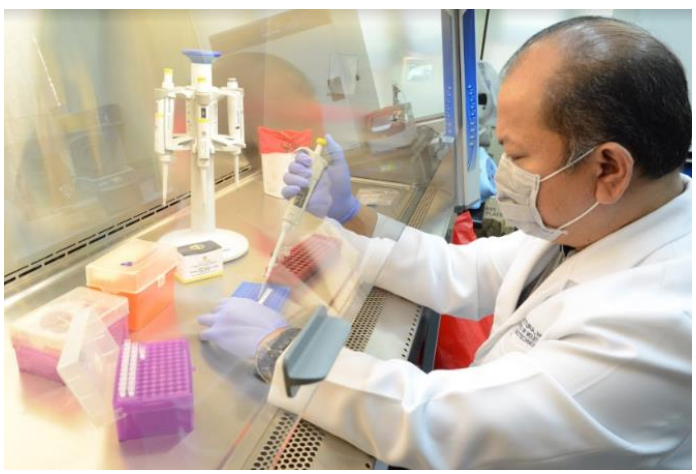
Scientific R&D outputs offer concrete solutions to address COVID-19 challenges

At the onset of the pandemic, the Philippines instantly developed new and redesigned existing technologies to aid the country in addressing the challenges brought by the COVID-19. The S&T solutions employed by the government, led by the Department of Science and Technology (DOST), can be categorized into immediate, medium-term, and long-term.

Immediate COVID-19 S&T Solutions

GenAmplify™ COVID-19 Testing Kit

The GenAmplify™ COVID-19 rRT-PCR Detection Kit was locally developed by Manila HealthTek and was supported by the Department of Science and Technology (DOST) and the Philippine Council for Health Research and Development (PCHRD). The detection kit offers a real-time detection of the novel corona virus (COVID-19) in respiratory samples using a one-step multiplex real- time PCR platform.



It is now mass produced after securing the approval from the Philippines' Food and Drug Administration (FDA). The kit has the advantage against its foreign counterparts as it is packaged completely with an RNA extraction device and viral transport medium that is not found in other testing kits.

RxBox Telemedicine Device

The RxBox was developed by researchers from the University of the Philippines-Manila-National Institutes of Health (UP Manila-NIH) and University of the Philippines-Diliman (UP Diliman). The RxBox is a biomedical device developed to measure the temperature, blood pressure, heart rate, oxygen saturation, uterine contractions, and electrocardiogram readings of patients diagnosed with COVID-19, especially those in severe or critical conditions who need continuous monitoring. This device protects both the patient and the attending healthcare worker as it reduces contact between them, providing an efficient way for the healthcare worker to monitor multiple patients at the same time.

FASSSTER

The Ateneo Center for Computing Competency and Research created Feasibility Analysis of Syndromic Surveillance using Spatio-Temporal Epidemiological Modeler (FASSSTER), a hub for different data sources, which provides a user-friendly tool for modeling disease spreads in the Philippines to aid the Department of Health's disease surveillance. FASSSTER takes a multi-dimensional modeling approach by using localized indices from Philippine health records and integrating other data sources including the disease and event surveillance systems and existing electronic medical records. It is also used to track number of ventilators, hospital beds, etc.

Specimen Collection Booths

The DOST, with its attached agencies Philippine Council for Health Research and Development (DOST-PCHRD) and Philippine Council for Industry, Energy, and Emerging Technology Research and Development (DOST-PCIEERD), also funded and supported the development of Specimen Collection Booths (SCB) to reduce the exposure of frontline health workers to suspected COVID-19 patients.

More than a hundred SCBs were produced and deployed to hospitals and facilities identified by the Department of Health. The design created by Futuristic Aviation and Maritime Enterprise (FAME) Inc. was released to the public, especially to the fabricators and engineers, to help augment the government's drive to beat COVID-19.

Medium-term COVID-19 S&T Solutions

Science and research are the world's chances for recovering better from the COVID-19 crisis. Aside from immediate response, the government must also undertake programs that would have a more lasting impact.

Addressing and Responding to COVID-19 through Health Research (ARCHER)

The program spearheaded by the DOST - Philippine Council for Health Research and Development (DOST-PCHRD) supports research projects that provide regulatory studies and solutions directed towards the development of new drugs and supplements, vaccines, diagnostic kits, prediction studies through Information and Communications Technology (ICT) and medical facilities' enhancement.

Science and Technology for a Resilient Community against the Pandemic (STRAP Block Grant)

The DOST - Philippine Council for Industry, Energy and Emerging Technology Research and Development (PCIEERD), is leading the STRAP Block Grant to help Filipinos adapt to the "new normal". Projects that will be funded in this program include the following:

(1) Work from home tools;
(2) Workplace Ergonomics;
(3) Safe mobility and transport – air, sea and land;
(4) Response and coping up with the new normal;
(5) Testing and calibration of locally-developed medical devices;
(6) Geospatial and ICT Solutions to address COVID-19;
(7) New devices and products;
(8) Protective Coatings for Surfaces and PPEs;
(9) Detection and disinfection technologies; and
(10) Emergency Food for COVID-19 affected families, communities, and frontliners.

Rebuilding the Agriculture, Aquatic and Natural Resources in Response to COVID-19 (ReAARRC)

The DOST – Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD) is implementing the Program "Rebuilding the Agriculture, Aquatic and Natural Resources in Response to COVID-19 (ReAARRC)" that aims to transfer technology and disseminate information to the public in terms of ensuring food security in this challenging time.

Long-term COVID-19 S&T Solutions

The pandemic has brought new challenges and heightened present issues being faced by different nations. Knowing that the effects of the COVID-19 will remain as obstacles in the future, the Philippines has started to initiate long-term solutions. Two (2) centers known as the Virology S&T Institute of the Philippines (VIP) and Pharmaceutical Development Centers, are being lobbied to be institutionalized to serve as the premier research and development institute in virology and drug discovery in the Philippines.

Technologies can serve as investments to boost competitiveness

The Philippines has been funding R&D projects, laboratories, and facilities to upskill the country's human resources and further capacitate the industry in terms of technological advancements.

Smarter Philippines through Data Analytics Research and Development, Training and Adoption or Project SPARTA

The DOST, through DOST-PCIEERD, developed Project SPARTA, in partnership with the Development Academy of the Philippines (DAP), Analytics Association of the Philippines, and CourseBank. Project SPARTA will produce 30,000 data scientists through free online education that will capacitate interested individuals with essential data science and analytics knowledge and skills to efficiently manage, analyze and interpret data. Project SPARTA is open to all Filipinos permanently based in the country, who are at least senior high school graduates, with or without prior knowledge on data science and analytics. Scholars may pursue one of these learning pathways: (i) data associate, (ii) data steward, (iii) data engineer, (iv) data analyst, (v) data scientist, and (vi) analytics manager.

Advanced Manufacturing Center (AMCen)

The AMCen aims to increase the country's technical readiness, business sophistication, and innovation rating by introducing one of the emerging technologies that is foreseen to greatly contribute in the country's goal of becoming globally competitive and to prepare the industry, including the academe, for increased research and development activities.

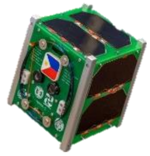
The Center's services include 3D printing services, engineering services, materials development, research services, and training services. The DOST, through the support of DOST-PCIEERD, DOST-Industrial Technology Development Institute (DOST-ITDI) and DOST-Metals Industry Research and Development Center (DOST-MIRDC) developed this first additive manufacturing research laboratory in the country. In the beginning of the pandemic, AMCen produced thousands of face shield frames through 3D printing and donated assembled face shields to various hospitals.

Advanced Mechatronics, Robotics and Industrial Automation Laboratory (AMERIAL)

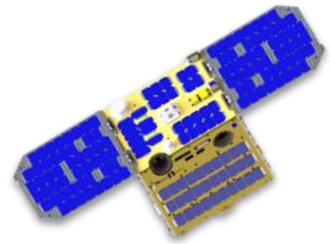
The AMERIAL aims to build capability in Industry 4.0 to help boost productivity in global competitiveness of the manufacturing industry especially the Micro, Small, and Medium Enterprises (MSMEs). The AMERIAL is envisioned to create a pool of skilled and highly qualified workforce, and to become an accredited training and development facility and service provider in industrial automation.

Space Science, Technology and Innovation

The Space Technology Applications, Mastery and Innovation (STAMINA4Space) Program undertakes research and capacity building on satellite development and operation in the country. The program components on payload development (OPTIKAL) and bus (PHL-50) develops technologies for small satellites targeting increased utilization of local materials and resources. For proliferation of know-how, the program component on establishing a university consortium (STEP-UP) makes use of cubesats and the ground station network as educational and research platforms for university collaboration. The operations group (GRASPED) continues managing the missions of two microsatellites, Diwata-1 and Diwata-2, as well as developing remote sensing products. Finally, the advanced satellite development component (A-SatDev) aims to build and launch a satellite system that provides data on a regular basis for applications on coastal habitat assessment, aquaculture monitoring, water quality monitoring, forestry management, wide area disaster damage assessment, land use and land change mapping, monitoring of crops and other agricultural products, ship and aircraft detection and tracking, infrastructure evolution mapping during crisis, and situational awareness during crisis, among others. Aside from the microsatellites Diwata-1 and Diwata-2, the Philippines also developed the cube satellites "Maya-1" and "Maya-2" that were launched in 2018 and 2021, respectively. The Program is funded by the DOST and jointly implemented by the University of the Philippines Diliman and DOST-ASTI.



The Philippine Earth Data Resource Observation (PEDRO) Center, being managed by the DOST-Advanced Science and Technology Institute (DOST-ASTI), operates three Ground Receiving Stations in the country. The PEDRO Center and STAMINA4Space Program closely monitored Typhoon Goni (locally called Super Typhoon Rolly); images and analysis on affected areas were distributed to key national disaster risk reduction and management (DRRM) agencies. Satellite images of major metropolitan areas were also captured during the start of the COVID-19 pandemic lockdown to monitor the situation of the traffic and other ground activities.



Through the projects and programs discussed under this section, the country aims to further upskill its experts in order to turn technical data, technological skills, equipment, and facilities into benefits for the Filipino people.

Implications of COVID-19 for science and technology-based emergency response in the Republic of Korea

Korea Research Institute of Bioscience and Biotechnology, Republic of Korea

The ongoing global health crisis is continuing to test the role of science and technology in overcoming disasters—it is clear that the COVID-19 pandemic can be tackled only with the help of effective treatments and vaccines. This suggests that science and technology have played a key role in appropriately responding to this new infectious disease and its emerging variants.

The key factor in the Republic of Korea's success in responding to COVID-19 is the establishment of a government-led national response system. In terms of science and technology, the Republic of Korea has strategically invested in basic research and effectively combined research and development (R&D) and infrastructure capabilities. As a result, diagnostic technology could be developed in time to contribute to effective infection control.

How could the Republic of Korea have enhanced its response to COVID-19 using science and technology? This brief aims to answer this question from the perspective of Korea Research Institute of Bioscience and Biotechnology (KRIBB), a government research institution. For COVID-19, KRIBB was able to zero in on its role and potential as an R&D platform that could be used to solve social challenges.

Importance of Basic Research in Responding to Unprecedented Challenges

Science and technology can provide a fundamental solution to the ongoing COVID-19 crisis. However, the biotech sector faces many challenges before reaching the final commercialization stage due to the nature of the industry, such as a long development time and the unpredictability of outcomes. Such problems notwithstanding, continuous basic research is the main reason behind the successful development of the mRNA platform-based vaccine in less than a year. The success or failure of the response to an infectious disease depends on meticulous preparation through mid- to long-term basic research.

In the Republic of Korea, the research base, developed through basic research capabilities, has played an important role in every major phase of the COVID-19 crisis. Based on MERS outbreak that took place in 2015 due to lack of rapid-responding systems, the Republic of Korea funded to diagnostic devices for early detection of COVID-19 cases. Followed by these efforts, the Republic of Korea was able to quickly produce diagnostic devices with accumulation of technical capabilities through continuous basic research. Over the past seven years, KRIBB and the BioNano Health Guard Research Center have developed source technologies and supported related companies through national projects. In addition, they have developed and supplied COVID-19-specific antigens since February 2020, as well as provided support in acquiring export permits and emergency-use authorizations for The Republic of Korea's antibody diagnostic companies through clinical validity evaluation.

Additionally, the country supplement to the Nature Index 2020 published in May 2020[60], commented that the Republic of Korea is transforming from a "Fast Follower" into a "First Mover" based on the fact that its fast development of COVID-19 diagnostic technology.

As a key national strategy for responding to unknown infectious diseases, one can conclude that continuous support for basic research that mostly comes with high-risks is required. To achieve this, the Defense Advanced Research Projects Agency (DARPA) model of the United States, which supports research for national security, is a good model to benchmark. The DARPA model provides exceptional support for high-risk research programmes, and enlists scientists and technologists from a wide variety of fields. Such actions can be introduced to develop the next-generation infectious disease treatment platform technology. In addition, as with the newly implemented enforcement decree of the national R&D act, Korea recently launched moonshot R&D projects with new attempt of implementing policies such as considering reasonable failures in the process of research assessment. For the successful implementation of these policies, a shift in social perception—that innovative basic research is absolutely necessary is paramount.

[60] Nature Index Annual Tables: Nature, Boosting South Korea's Basic Research, May 27, 2020

Establishing Industry-academia-research Support Platform for Accelerated Outcomes

Looking back over the past year, the spread of COVID-19 has been faster than any other infectious disease in recent history, and it has had a significant global impact. Active cooperation among those engaged in basic research, preclinical, clinical, and licensing areas is required until the research results are applied on-site (e.g., in hospitals). To ensure effective and accelerated achievement of goals, a one-stop R&D platform that links various innovative actors should be established.

The Republic of Korea has established a science and technology-based crisis response system in which industry, academia, research institutes, and hospitals work together, with government research institutes at the center. A total of 13 government research institutes, including KRIBB, have divided the work according to each organization's expertise. The government has funded these organizations through supplementary budgets. In addition, regulators have drastically shortened the mandatory screening period and supported patient application by utilizing emergency-use authorization system.

KRIBB is the fourth in the world to develop the primate infection model, thus establishing the early system supporting industry, academia, and other institutions; it has also supported evaluation of the COVID-19 vaccine efficacy using primates and hamsters—as a result, preclinical evaluation of 39 excellent candidate substances was completed, and the world's third approved COVID-19 antibody treatment drug called Regkirona (regdanvimab, also known as CT-P59) was developed. One of the unsatisfactory aspects of these activities, however, is that the infrastructure support has not benefited many innovative actors. For example, only 12% of the preclinical evaluations of primates, essential for developing effective treatments and vaccines, was funded by the government despite the high demand. Therefore, the expansion of high-risk infectious disease research facilities with a vision of open innovation is essential to prepare for future pandemics and meet the demand for R&D by various industry-academia institutions. And another crucial lesson and proposal after looking back past few months of responding to COVID-19 would be the development of all-purpose technology that can be utilized in response to variants of new infectious diseases.

Promoting Research Information Sharing for More Effective Research

With the COVID-19 pandemic triggering the digital transformation of R&D, the importance of sharing research information has been highlighted for accelerated outcomes. Recently, biotech big data such as genomes, metabolites, and clinical data have been combined with artificial intelligence technologies to drastically reduce the time and cost of developing treatments and vaccines. In particular, results of studies of infectious diseases should be shared among multiple entities as they have public good characteristics, unlike other fields.

KRIBB has increased access to research information through one of its research groups, Korea Bioinformation Center (KOBIC). KOBIC has provided real-time information (approximately 500,000 cases) on the COVID-19 virus genes and proteins collected from the National Center for Biotechnology Information of the United States, European Bioinformatics Institute, Protein Data Bank, and World Health Organization's GISAID database. In addition, it has provided analysis services for comparative analysis of exome sequence, lineage, and various mutations through its website.[61] For the general public, it has set up the website "Corona 19 A to Z" to provide scientifically verified information.

Technology development in response to COVID-19 began in earnest after the entire genome analysis of the virus was released a month after the first case was reported. It is thus evident that increased access to research information contributed to the rapid performance. Thus, the future direction of R&D is to broaden the scope of sharing and cooperation and make it sustainable. Korea integrates and provides research data through the "National Bio Data Station." In addition, it has been planned that research data will be produced and shared according to the Data Management Plan. As such, sharing research information needs policy- and social-level support because it extends beyond a topic of interest for scientists. In the future, systems such as providing incentives for information sharing should be established, and a culture that encourages voluntary sharing should take root.

The COVID-19 pandemic has served as the starting point for Korea to gain confidence in its scientific and technological capabilities to overcome the global crisis. The country shares this experience and capability as a

[61] www.kobic.re.kr/covid19/

responsible member of the international community.

KRIBB will expand its cooperation system to other research institutions to combat the crisis beyond Asia through international networks established to tackle an infectious disease, such as the Global Research Collaboration for Infectious Disease Preparedness (GloPID-R). In addition, it will actively contribute to the development of technologies for achieving the UN Sustainable Development Goals, which extend beyond infectious diseases and embrace the universal values of mankind. We are looking forward to meeting innovative players around the globe on the way to our future initiatives.

COVID-19 responses and their implications in the Republic of Korea compared to Japan, New Zealand, Germany, Sweden, and the U.K.

LEE Hanjin and MOON Aree, National Research Foundation, Republic of Korea

Abstract

The COVID-19 pandemic has collapsed global value chains (GVCs), exacerbating income disparity among people as well as countries. This article aims to examine and analyze the various COVID-19 response strategies and policies in the Republic of Korea and other key countries, including Japan, New Zealand, Germany, Sweden, and the U.K., and explore the adequacy and distinction of current strategies and policies adopted by the Republic of Korea, thereby outlining policy implications and measures for the future.

Note: This report is based on "Living in the age of COVID-19: key countries' responses and their implications" by LEE Hanjin and MOON Aree in KISTEP InI, 2021.

Analytical Model

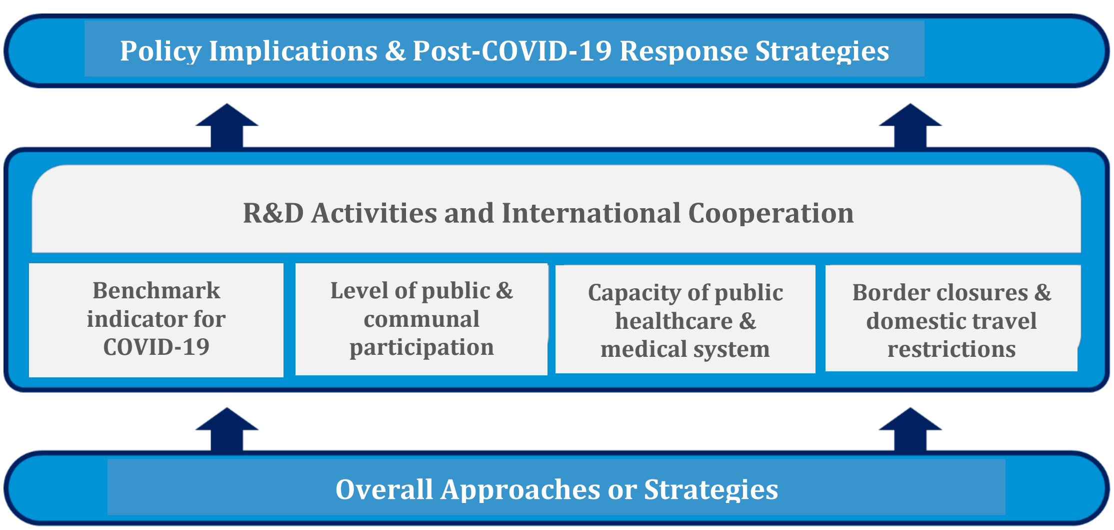
Different countermeasures and policies to combat the spread of the novel COVID-19 infections have been adopted depending on each nation's healthcare systems, status of culture, economy and society. This research divides analytical factors into five categories under an analytical model below, based on each country's approaches and strategies.

Current status by country and key indicators

Benchmark indicator for COVID-19 infections

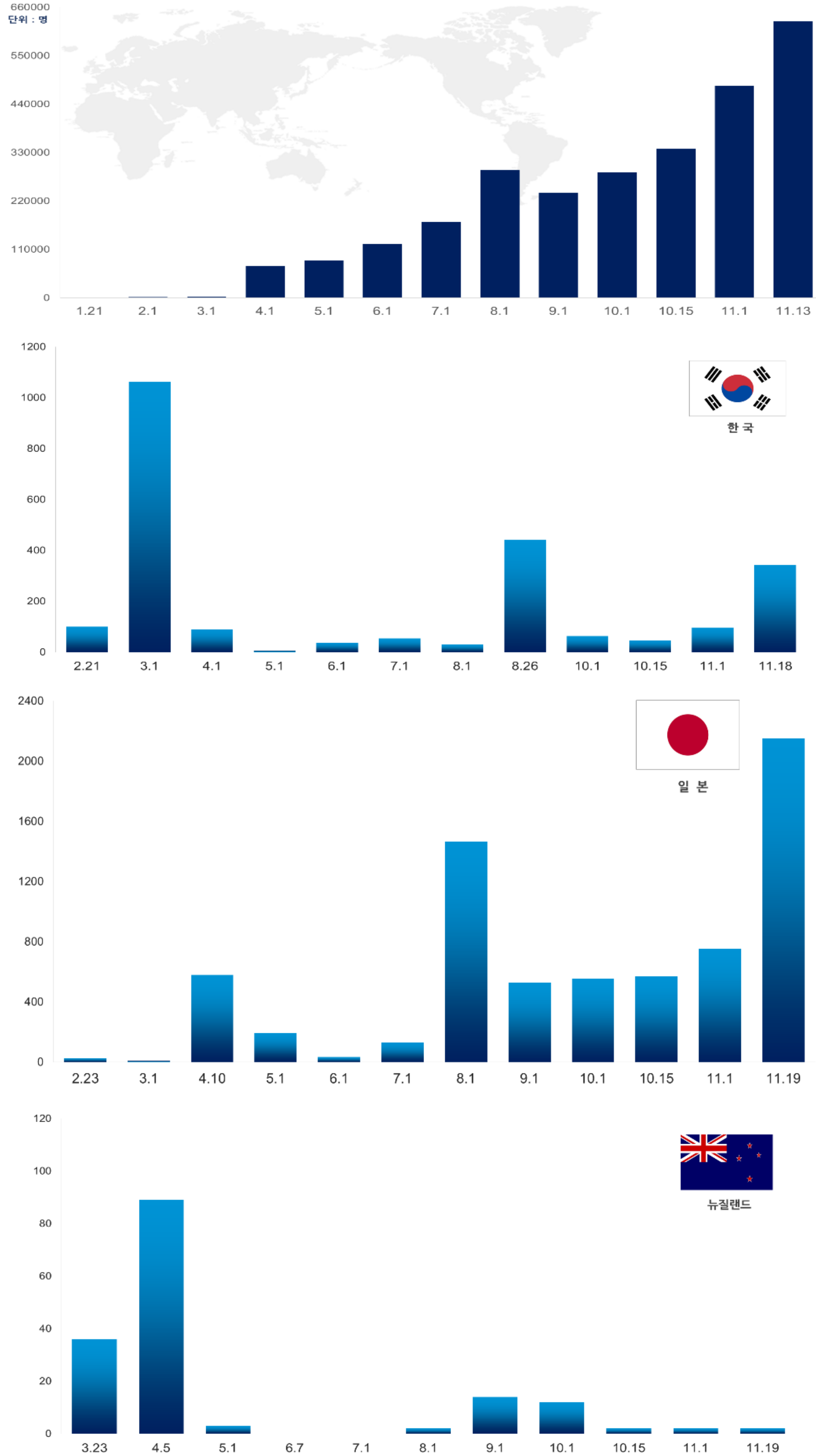
Indicators for the coronavirus infections are what helps a nation tackle transmission in timely and suitable manner as they may be the reflection of its close monitoring of virus spread and transparent communication with the public. Initially, the Republic of Korea divided the level of contagion into three stages: Level 1 (fewer than 50 new confirmed cases a day), Level 2 (50-100 new confirmed cases a day) and Level 3 (100-200 new confirmed cases a day). The Korea Disease Control and Prevention Agency (KDCA), infection management authority, later finalized its five-level restrictions, by adding Level 1.5 and 2.5 as of November 7, 2020. The addition reflected a shift in the nation's policies to brace for a protracted battle against the coronavirus, easing the restrictions and expanding social and economic activities (KDCA, November 5, 2020). On the other hand, Japan's indicator monitors the weekly number of infections per 100,000 people, aiming to contain the level to under 0.5.

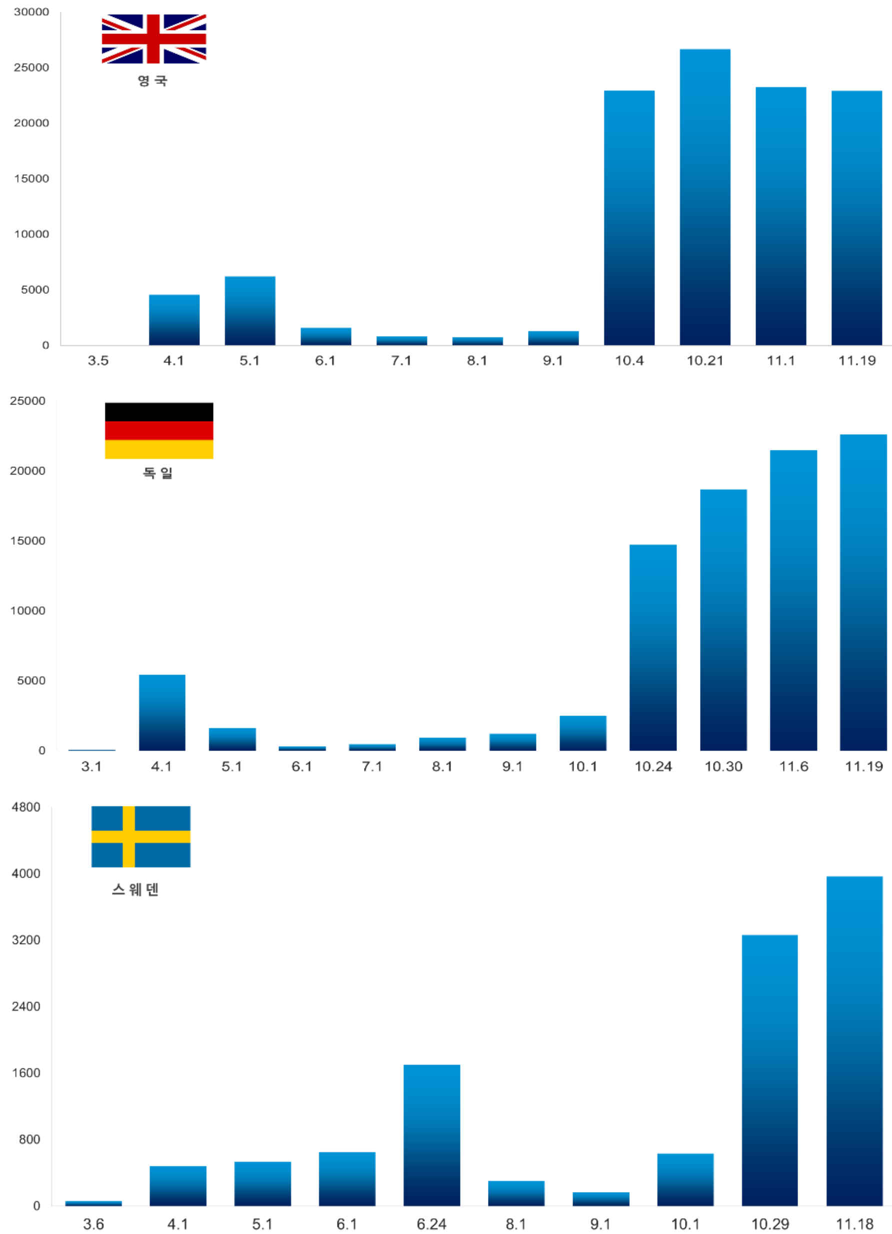
Figure 1: COVID-19 Analytical Model of Key Countries' COVID-19 Responses



Source: The analytical model is modified from the one used in the paper "Lessons learnt from easing COVID-19 restrictions: an analysis of countries and regions in Asia Pacific and Europe," Health Policy, published online on September 24, 2020, at https://doi.org/10.1016/S0140-6736(20)32007-9.

Figure 2: Number of confirmed cases by country

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3.6
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5.1
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9.1
10.1
10.29
11.18

Source: WHO

New Zealand opts for the four-level alert system: Level 1 (preparation against the spread of the virus), Level 2(response to a highly risky situation of community transmission), Level 3 (restriction of the nationwide spread) and Level 4 (lockdown to contain the fast and continuous spread) (PARK Nayeon, 2020). Sweden, instead of setting nation-wide mandates or restrictions, encouraged public freedom and autonomous containment protocols of its districts, and advised its public to refrain from gatherings of more than 50 people, frequently washing hands, staying at home when feeling unwell, and urging distance learning or attending classes from home (Tove F., 2020). The U.K. and Germany utilize basic reproduction number (R), the mean number of new infections caused by a typical infected individual during a specified period, to determine their COVID-19 alert level. In addition to the R index, Germany also tracks the number of new infections per 100,000 inhabitants in seven days (Emeline H. et al., 2020).

Public and communal participation

The public and the community's level of participation regarding government mandates and restrictions differ predominantly between Asia and Europe. South Koreans and Japanese people actively wear masks, practice social distancing and self-isolation, and avoid 3Cs (Closed spaces, Crowded places, Close contacts) to help tackle the spread of the virus.

New Zealand successfully kept the outbreak in check with the concept of a "social bubble," becoming the first country to lift its coronavirus restrictions in June 2020. The idea was later benchmarked by other countries, such as Canada, Belgium, Germany, and the U.K.

The U.K's restrictions – wearing a mask and staying at least one meter apart – faced a backlash due to a social and cultural aversion, which has restricted the efficacy of containment protocols. Since March 23, 2020, Germany mandated to wear masks in public, and adopted a 1.5-meter social distancing rule and selective measures already in place in Asian countries, emerging as a model country among those in Europe.

Sweden has maintained the principle of pursuing the autonomy of local governments in regulations yet interfering with the free will of its citizens as little as possible. Instead of restricting or prohibiting the public's freedom of movement, its government just recommended remote working, self-isolation, and discouraged gatherings of more than 50 people. Stockholm's initial response, once concerned by other countries, has become a subject of-revaluation, with some experts asserting that its policy was a testament to democracy in action even during the crisis.

Public healthcare and medical system

The Republic of Korea tracks the movement of someone with COVID-19 and alerts others who may have crossed paths with the patient by utilizing phone interviews, hospital records, credit card usage, video surveillance, and even global positioning system (GPS) history on individuals' smartphones. Korea's high-tech monitoring system was crucial for flattening the curve swiftly during the initial outbreak. Yet, some at home and abroad have expressed concern that such practices infringe on the right to personal privacy and democratic principles.

The capacity of each country's medical system depends on its standard of tests and treatment and a sufficient supply and procurement of medical equipment. This ranges from intensive care units (ICUs) at hospitals to regional medical facilities that can provide treatment and ventilators for patients and protective gears for front-line workers. The Republic of Korea with an ample supply of test kits to conduct mass tests, quickly introduced various innovative testing means, such as drive-through and walk-through testing stations, emerging as a global leader in the field.

Border closures and domestic travel restrictions

New Zealand, Taiwan, Singapore, and Hong Kong which are the first ones to lift restrictions, successfully containing the COVID-19 spread (June 8, 2020) by restricting or denying entry to their borders at the onset of the global outbreak. The Republic of Korea and Japan currently require inbound travellers to go through a mandatory 14-day quarantine period before moving freely within the country. By comparison, European nations were reluctant to enforce border restrictions or lockdowns at the start of the global pandemic. As infections surged in March and April 2020, the World Health Organization's Director-General Tedros Adhanom Ghebreyesus pinpointed Europe as the global pandemic epi-centre, prompting European governments to rush to close their borders.

Advances in research and development (R&D) and international cooperation

The aforementioned countries are conducting R&D to enhance their basic knowledge of COVID-19, improve their testing efficiency, and develop effective vaccines. Through its state-run National Research Foundation's

Rapid Response Research (RAPID) program, the Republic of Korea is funding relevant one- to two-year studies. It is planning to form a task force to respond and prepare for viruses and contagious diseases, conducting studies on "Disease X," representing an as-yet-unknown pathogen that could be the cause of a severe global epidemic in the future (NRF, August 2020).

Tokyo has tasked its state-run Japan Agency for Medical Research and Development (AMED) to take the lead in developing efficient testing measures and kits, conducting research on pathology and epidemiology, creating vaccines and funding international cooperative studies as well as taking part in Group of Seven (G7) meetings involving leaders in the scientific field (April 30, 2020), thereby boosting international cooperation (AMED, August 11, 2020). The U.K.'s Medical Research Council (MRC) is extending resources and duration of grants through its "COVID-19 Grant Extension Allocation" endeavor and shifting toward the Revering and Learning program from its existing Rapid Response Rolling initiative (MRC, November 10, 2020).

German Research Foundation, also known as Deutsche Forschungsgemeinschaft (DFG), developed its COVID-19 Focus Funding program in August 2020, offering grants for studies on topics chosen by the Commission for Pandemic Research (DFG, August 10, 2020). The Robert Koch Institute (RKI), a German federal government agency and research institute responsible for disease control and prevention, provided assistance on public health aspects to more than 60 countries in Africa, Asia, Europe, and Latin America (RKI, June 2020).

Meanwhile, according to “UN Research Roadmap for the COVID-19 Recovery”, the global pandemic has added momentum to the de-globalization in recent years, adversely affecting international trade. Nevertheless, the report noted achieving the U.N.'s sustainable development goals (SDGs) depends on a global partnership to recover from the pandemic.

Implications on Future Policy

We have previously outlined the strategies and policy responses adopted thus far by the Asia Pacific and European nations, provided research and analysis on civic participation and each of the key countries' healthcare and medical capacity. Through this process, we can arrive at implications on the policy applied in the future.

Firstly, the Republic of Korea's initial protocols were insufficient to handle the alarming spread of COVID-19, resulting in the highest number of patients testing positive for the virus outside China, and prompted many countries to ban or restrict Koreans' entry. However, its speedy and cooperative actions to manufacture and distribute test kits and conduct mass testing through distinctive testing methods mentioned earlier, garnered global attention, allowing it to expand its role as a global leader in the future.

Secondly, the pandemic has shed light on cultural differences between Asian and European countries in their responses. European expressed a strong aversion to mandates and restrictions – wearing masks, self-isolation and lockdowns, relying on the individual judgement and the autonomous districts' guidelines to contain the pandemic, which may appear negligent to many Asians more accepting the same measures. Europeans, however, may have found it challenging to understand the methods employed by the Republic of Korea and other Asian nations to closely track and surveil its citizens using the cutting-edge technologies.

Finally, we should note the correlation between the economy and efforts for coronavirus containment. Tighter restrictions and protocols accelerated the economic downturn. In its report on Global Economic Prospects, the World Bank forecasts a 5.2 percent average contraction for the global economy in 2020. U.S. and European economies are expected to post negative growths of 6.1 percent and 9.1 percent, respectively. New Zealand, declaring itself from COVID-19, will likely see its GDP declined by 10 percent. The correlation between a nation’s economy and its infection containment efforts cannot be easily defined but it is axiomatic public health and safety should always come first.

How should we strategize for a post-COVID-19 era? Firstly, we should envision a society co-existing with the virus. In a post-pandemic world, a non-contact community and online daily routines will become the norm. Secondly, countries around the world should prepare for a paradigm shift toward a non-contact society, embracing an era of Digital Transformation. Thirdly, COVID-19 has left the world with tricky issues such as governments’ pandemic restrictions and individuals’ right to privacy and freedom, and the advent of totalitarianism and economic recession. All nations and their citizens need to strive to break free of totalitarian views and digital surveillance to ensure humanity's universal value of personal freedom and democratic order. Only with a balanced perception and cooperation between the state and individuals can humankind move forward for a better society.

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Update from ICGEB: SARS-CoV-2 surveillance, developing alternative diagnostic tools, and providing technical expertise

International Centre for Genetic Engineering and Biotechnology (ICGEB)

Note: The views expressed are those of the authors and do not necessarily reflect those of the United Nations or its senior management.

Abstract

The ICGEB actively contributes to transforming basic research findings into practical solutions. In the current pandemic, this has been achieved by performing SARS-CoV-2 surveillance, developing alternative diagnostic tools (point-of-care and portable) and providing technical expertise and know-how that benefit its Member Countries, particularly those in low resource settings. This paper presents the main projects and the lessons learned from the basic and translational research. We conclude by sharing our recommendations relevant for the science-policy-society interface.

Public-private partnerships to fight the pandemic and open science – empirical facts and issues

The ICGEB's response to the COVID-19 pandemic has been coordinated along three different lines of support:

1. to local health authorities, by supplying diagnostics and sequencing the circulating virus;
2. to the ICGEB Membership, by providing training, transfer of expertise, and promoting local capacities for facing the COVID-19 emergency; and
3. to the scientific community, through advanced basic research and sharing resources in open access.

In March 2020, the ICGEB Molecular Virology team, working in the only Biosafety level 3 (BSL3) laboratory in the Region, was one of the first to isolate and sequence the full genome of SARS-CoV-2 in Europe. This allowed (i) a better understanding of the genetic evolution of the virus in Northern Italy; (ii) the setup of molecular and serological assays for SARS-CoV-2 that are essential to identify infected individuals and those who have recovered; (iii) further research on antiviral drugs and vaccines.

Subsequently, the ICGEB launched an online Open Access Covid-19/SARS-CoV-2 Resource Platform to provide tools and expertise, free of charge, to fight SARS-CoV-2.[62] The platform provides information on procedures (backed up by virtual technical assistance) for the isolation and detection of Sars-CoV-2 RNA, and for the production of essential reagents that can be developed 'in house'. The ICGEB resource platform includes protocols for diagnostics and reagents for RT-PCR. By providing free access to reagents that are normally unobtainable without using commercial kits, the platform has eliminated many of the financial barriers to the analysis of the virus. The platform also includes on-line video tutorials from ICGEB scientists to explain the various methods of isolating viral RNA, or producing positive control viral RNA samples, for the development of new diagnostics.

In parallel, the ICGEB has promoted and forged public-public and public-private partnerships to transform basic research into much-needed solutions, for the development of antiviral drugs, diagnostics and implementation of workplace preventive measures.

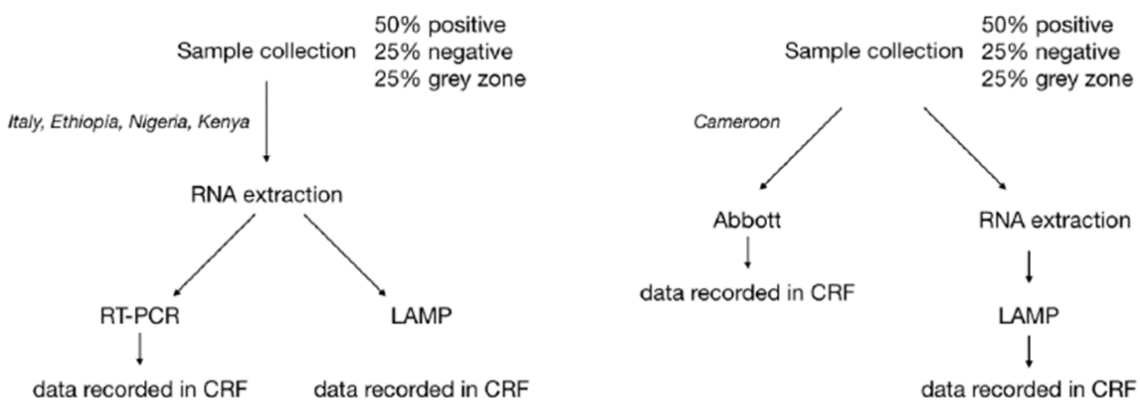
When fighting a viral pandemic, the early detection of infected persons is the key to allowing the swift deployment of necessary measures. Currently, Sars-CoV-2 infection is mainly diagnosed using RT-qPCR to detect the viral RNA from swabs. This is highly efficient and specific, but is mostly tailored to well supported health systems and technologies. In low and middle-income countries (LMICs), this approach is often not possible, owing to the high cost and limited availability of materials, such as RNA extraction kits, and poor physical infrastructures. Very recently, new colorimetric detection methods of detecting Sars-Cov-2 have been developed, requiring only basic equipment. These tests are technically simpler, and cheaper than setting up a RT-qPCR lab. They also require neither highly-specialized personnel, nor frequent technical

[62] https://www.icgeb.org/covid19-resources/

maintenance. Therefore, their use could be a game-changer in low-resource settings.

To meet LMICs' need for reliable, affordable and sustainable diagnostic tools, the ICGEB has promoted a public-private partnership; whereby a private company, New England BioLabs (NEB), that produces a new colorimetric detection method for Sars-Cov-2 has provided testing materials to selected reference laboratories in African LMDCs. ICGEB's task has been to coordinate the transfer of materials, the training, the identification of the laboratories and the scientific network. Financial support was obtained from the Bill & Melinda Gates Foundation (BMGF). The pilot project's overall objective is to enhance the capacity of laboratories in LMICs to respond to SARS-CoV-2 through improved rapid diagnostics programs. The countries targeted in this pilot phase are Cameroon, Ethiopia, Kenya and Nigeria - specifically its northern province of Maiduguri, Borno State - where a number of laboratories and scientists were identified and engaged. The diagnostics tools present a further advantage, being easily applied to other infectious diseases and outbreaks.

Figure 1 shows the basic scheme of the study conducted in parallel in the ICGEB laboratories in Trieste and in the reference laboratories in selected LMICs.



Source: Project Progress Report "COVID-19: Establishing rapid laboratory diagnostics programs in LMICs"

The final results of the project are expected by the end of March 2021, and preliminary results are extremely encouraging. There is a growing demand in other African countries to scale-up our intervention.

A key element in a pandemic response is speed and flexibility. Through the ICGEB Grant funding programme a call for Covid-19 related research projects was launched in April 2020, and selection procedures were completed by August 2020. In partnership with Instituto Italiano Latino Americano (IILA) we were able to support a total of 9 research projects on Covid-19 in low resource settings, and which were able to commence by October 2020. In these project, teams of scientists are supported working on problems specifically relevant to their own geographical locations.

The ICGEB also collaborates closely with Sun Pharmaceutical Industries Ltd., the world's fourth largest and India's top pharmaceutical company, to test their plant-derived drug for the treatment of COVID-19. This is the first phytopharmaceutical drug approved for a clinical trial by the Drug Controller General of India (DCGI) for COVID-19, and the Clinical trial is ongoing across 12 centres in India.

Further, a successful public-private partnership was forged with MSC Cruises and Fincantieri, whereby ICGEB scientists collaborated with Fincantieri's designers in developing an advanced air sanitation technology "Safe Air", to improve the air quality on cruise ships. The ICGEB provides scientific support to businesses, in developing innovative technological solutions for the ongoing control of emerging virus infections; particularly relevant in the current global health and consequent economic crisis. This new air sanitation system is based on UV-C lamp technology within the air conditioning system. Thus, the air flow will be irradiated at source with type C ultraviolet rays, to destroy and prevent circulation of biological air pollutants, such as viruses, bacteria and moulds.

Policy recommendation

The lessons learnt by ICGEB from implementing these projects suggest some important elements for policy recommendation:

1. It is critical to adapt emerging technology to local settings, by working closely with Governments and scientists in defining local needs, priorities and limitations. ICGEB's actions in fighting the spread of the virus have been conducted, on multiple fronts (detection, treatment, immunisation, prevention), and in multiple settings (including low-resource, geographically remote locations with scarce health infrastructure). To fight effectively against the virus entails structural adjustments and adapting the STI tools to the local needs. Therefore, the added value of ICGEB's research and novel STI applications are best highlighted in tailoring technologies to fit low resource settings and in meeting the needs of its Member Countries. This includes the use of affordable, portable and easily interpretable, yet reliable, testing tools. Particularly relevant is the removal of barriers to research, by circumventing the need for commercial kits, and fostering open-source tools and protocols. These projects have directly tackled SDG9.5 by enhancing scientific research and upgrading technologies, with a focus on developing countries.
2. Diversifying the applications of STI in the fight against COVID-19: for example, enhancing the use of affordable COVID-proof air-sanitation systems as preventative measures in essential locations (schools; retirement homes; hospitals, etc.), can prevent disruptions of essential social and economic activities (schooling; food production; energy supply). In this context, scaling-up local production and local use of health technologies to combat COVID-19 (SDG9.5) are critical; and also ensure the equitable access to essential technologies (SDG10).
3. Committed to realizing SDG 17, the ICGEB actively promotes public-private partnerships to make its activities inclusive, sustainable, deliverable; promoting access to science, technology and innovation to all its Member Countries, and beyond. Such collaborations bring synergies and directly support research and development where it is most needed. The ICGEB is also proactive in South-South cooperation, whereby the LMICs actively develop and exchange knowledge and assist each other, rather than being perceived solely as beneficiaries.
4. Access to STI solutions and scientific capacity-building are pressing issues, particularly in LMICs, which are less prepared in terms of infrastructure, human capital and expertise. An inclusive and coordinated approach to strengthening LMICs' capacities to respond to COVID-19 and to increase their access to lifesaving health technologies, especially research, treatment and testing capabilities, is essential. ICGEB's input to the SDG 4 focuses on providing open science and universal access to all its resources, adding newly acquired expertise in real-time, as well as focusing on scientific capacity-building and direct technical assistance. Due to the current travel restrictions, ICGEB has developed on-line video-based training programmes for ICGEB technologies, to ensure continuity with its training and capacity-building activities, including the technologies for biosimilars' production and related bio-analytical services.

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Update from CANEUS, FILAC and OOSA: Lessons from COVID-19 and adapting frontier technologies with indigenous knowledge

Milind Pimprikar, Canada-Europe-US-Asia-Africa Organization on Emerging Space and Micro-Nanotechnologies for Societal Applications (CANEUS); Myrna Cunningham and Gabriel Muyuy, Fund for the Development of Indigenous Peoples of Latin America and the Caribbean (FILAC); Simonetta Di Pippo, Shirish Ravan, Luc St-Pierre, and Markus Woltran, UN Office for Outer Space Affairs (OOSA)

Abstract

With the challenges of accelerated technological inequalities amongst Indigenous Peoples, there is an urgent need to bridge the gap with these imbalances, including language barriers and gender inclusion with the frontier STI community.

Emerging technologies-based tools and solutions which include space-based data and artificial intelligence can play a major role in providing transformative pathways to meet the socio-economic and environmental challenges. However, to reap the potential of these emerging concepts and accelerate their infusion into societal applications, a coordinated approach integrating stakeholder's complimentary competencies becomes essential.

This science-policy brief presents empirical evidence acquired from series of global collaborative efforts representing Indigenous communities and key actors in the field of EO & ICT, which were launched, and undertaken during the COVID-19 pandemic, to create a platform to identify the challenges and opportunities to develop and implement culturally relevant space-based tools enabling its widespread impact on climate change and youth empowerment.

Introduction

CANEUS, FILAC, and UNOOSA are working together to help the Indigenous communities bridge the gap with technological equalities, specifically hands-on training, and capacity development using emerging EO technologies.

FILAC the only Indigenous "Inter-Governmental" organization with Permanent Observer representation at the United Nations, is empowered to develop solutions to current challenges to serve the needs of Global Indigenous communities. CANEUS, Permanent Observer Member of the United Nations Committee on the Peaceful Uses of Outer Space, is mandated to develop emerging EO technologies-based solutions to serve societal needs through Public-Private partnerships. The United Nations Office for Outer Space Affairs (UNOOSA) focuses on inclusiveness as an underlying factor in sustainable development while bringing benefits of space to humanity.

CANEUS and UNOOSA contributed to UNFCC's Resilience Frontiers Indigenous initiative which brought together 100 emerging technology leaders through Songdo brainstorming conference in April 2019. CANEUS, FILAC and UNOOSA also contributed the UN Secretary General's Indigenous Climate Action Summit held at UN-NY on Sept 21-22, 2019[63]. It was followed by a side event "Indigenous Peoples-led Use of Earth Observations"[64] at UN-HLPF 2020 (UN High Level Political Forum).

These efforts further steered using the "Guidance Note for the UN System prepared by the UN Inter- Agency Support Group (IASG) on Indigenous issues" in April 2020, which recommended that the UN system engage with Indigenous Peoples and promotes their participation through traditional knowledge with science experts.

Rationale

This input to the IATT report highlights the lessons learned during the Covid-19 pandemic with reference to the use of emerging EO-based solutions which are relevant to indigenous communities that are vulnerable due to climate extremes.

Indigenous Peoples want sustainable solutions from the perspective of their Indigenous science and knowledge, possibly through their own institutional and organizational mechanisms. Therefore, the global STI community need to involve Indigenous knowledge in

[63] http://www.iipfcc.org/blog/2019/11/3/world-indigenous-peoples-present-climate-action-commitments-at-unsg-climate-action-summit
[64] http://www.caneus.org/unhlpf2020
https://caneus.org/Report_UN_HLPF_2020_Side_Event.pdf

the process, at the same time, Indigenous Peoples need to adapt emerging frontier technologies.

There is a need to examine and identify challenges and barriers for Indigenous communities to implement workable and replicable emerging technology-based solutions. For example, spatial and temporal nature of the space-based information provides a better understanding of the scenario and influence the decision-making process to help research, policies, and programmes.

Thus, this input also offers IATT an opportunity to update progress on Article #15 of the WSIS Declaration of The World Summit on the Information Society, stipulating that "In the evolution of the Information Society, particular attention must be given to the special situation of indigenous peoples, as well as to the preservation of their heritage and their cultural legacy".

Objectives

To reduce the sense that frontier technologies have been overlooking Indigenous peoples as active participants in attaining the SDG's, as opposed to mere recipients. Specifically, with the emergence of the global data revolution and associated new technologies are a double-edged sword for indigenous peoples.

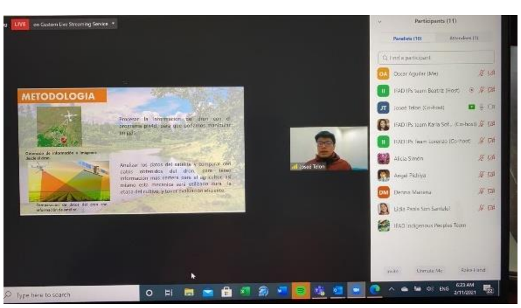
To convert the regional collaborative effort using the lessons learned during Covid-19 pandemic, as scalable and replicable worldwide, aimed to address the technological inequalities amongst Indigenous Peoples, techno-cultural complexities, and the role of emerging EO and AI based tools and solutions that have high relevance to complement Indigenous knowledge for economic, social, and environmental dimensions of sustainable development.

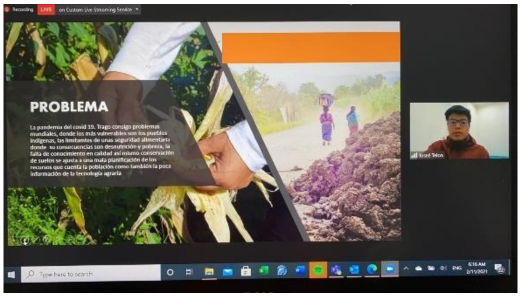
Implementation

The activities were implemented in phased approach.

A. The initiative was launched as a side event at UN HLPF 2020 by mobilizing stakeholders and partnerships to offer sustainable innovations, and access to technologies to address the issues of inequalities relating to technological imbalance, language barrier and gender inclusion.
   - It aligned with its theme "Accelerated solutions for Indigenous Peoples 2030 agendas using EO based solutions".
   - 20 experts and 454 participants representing Indigenous communities and space technology sectors shared methodologies, experiences and lessons learned that can support key areas of land/ocean/seas.
   - The crossdisciplinarity input also offered insight on broader issues, e.g., technology gaps and the pandemics, innovation challenges, need for empowerment of youth, and Indigenous capacity development in decision-making, and data sovereignty.
   - It specifically helped to identify focused activities, e.g., pilot projects, training programs as well as challenges covering climate change, food security, amongst others, which are being pursued through FILAC-CANEUS 5-year 2021-2025 cooperation agreement supported by UNOOSA.

B. In the second phase, a global challenge "leave no one behind" was designed and undertaken by UNOOSA, FILAC, CANEUS and CNES, ESA.
   - The challenge was to design a solution using one or a combination of satellite-based technology to mitigate the near and long-term impacts on food production of COVID-19 pandemic on indigenous communities.
   - 70 Participants representing young Indigenous students and entrepreneurs from 21 countries responded to the global challenge and four teams devising innovative solutions.
   - The winning team has been offered an opportunity to present at the UN Food Systems Summit in Sept 2021.





C. Now, during the ongoing phases, CANEUS, FILAC and UNOOSA are working to create a capacity building platform to address the accelerated technological inequalities with "leave no-one behind" using EO based tools and solutions and Ecosystem-based Disaster Risk Reduction (Eco-DRR) that has high relevance to complement the knowledge of Indigenous communities, by leveraging several initiatives like "Access to Space 4All" and "Space Economy".
   - A recent study by the three organizations for Global Assessment Report (GAR) 2022 reviewed potential of emerging EO in providing simplistic and operational tools for the systemic risk analysis to complement the Indigenous Knowledge covering nature-based solutions.
   - It analyzed relevant international frameworks and instruments in the context of role of indigenous communities and the role of emerging EO based tools and solutions in building disaster resilience.
   - The study also underlined the gaps and practical barriers that impact the exchange between Indigenous and local community knowledge holders, and emerging EO based tools and solutions developers and providers.
   - It recommended that EO community needs to develop the perspective to integrate emerging EO-based information products and knowledge of indigenous community.

Challenges

Challenges for integrating emerging technologies and Indigenous knowledge for the implementation of SDGs at National and local levels include:

a. The issue of linking emerging technology-based tools with Indigenous knowledge and effective ways to balance such practices.
b. The key "Principles" working with Indigenous Peoples, e.g., importance of respect for different knowledge systems and mutual learning from each other.
c. The importance of existing tribal and Indigenous data governance protocols and procedures.
d. The importance for developing the tools to support the local language needs, and challenges with the "technical terms" which may be discouraging to local practitioner.

The knowledge possessed by Indigenous community is valuable and can be further complemented by emerging technology-based solutions that focus on ecosystem and environment with great relevance to needs and knowledge of the indigenous communities. It also underlines the gaps and practical barriers that impact the exchange between Indigenous and local community knowledge holders, and emerging technology-based tools and solutions developers and providers. The technological inequalities appear growing especially due to Covid-19 pandemic and it would be challenging to meet the indicators defined by the SDG's.

Results and Key Policy Recommendations

The results from the completed and ongoing activities offer following key measurable impacts by contributing to bridge the technological and gender inequalities.

1. Empowering Indigenous communities from 21 countries with emerging technology-based solutions.
2. Focused programs through Indigenous Intercultural University to address the accelerated technological inequalities.
3. The "leave no-one behind" challenge having long-term impact on sustainable food systems as well empowerment of youth.
4. Formulation of dedicated multi-year program for integrating EO and Indigenous Knowledge for accelerating SDG implementation.

The key messages include:

(a) the knowledge possessed by Indigenous community is valuable and must be documented or archived by employing frontier technologies to collect, assimilate and reproduce it before it disappears due to the developmental pressures coupled with risks posed due to climate change,
(b) the knowledge possessed by Indigenous community should be complemented to emerging technologies-based solution for SDG implementation, and
(c) the results underline the gaps and barriers impacting technological inequalities which appear growing especially due to Covid-19 pandemic and the challenges to meet the 2030 targets.
(d) the need to establish mechanisms that protect the collective property rights of indigenous peoples, which are used without their authorization, especially the cultural heritage related to their textiles.

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IV. Emerging science and frontier technologies for the SDGs

This chapter puts forward a number of issues that require attention of policy makers. It reflects on achievements and failures of emerging science and frontier technologies during the COVID-19 pandemic. It features perspectives of individual TFM stakeholders, including the 10-Member Group, IATT members, and other external contributors, and summarizes them. It provides a space for bringing together individual and organizational inputs, findings and recommendations on emerging science and frontier technologies for the SDGs.

Following an overview of the contributions (Section III.A), six different types of contributions are presented: policy briefs on the big picture of science and technology policy issues (Section IV.B); on digitalisation, artificial intelligence an robotics (Section IV.C); on big earth data, satellites and remote sensing (IV.D); on environmentally compatible frontier technologies (IV.E); as well as specific solutions and updates on country experiences and activities (IV.F); and findings and recommendations of selected UN flagship publications (IV.G).

A. Overview

Seven science-policy briefs presented here take a big picture view of science and technology policy issues.

Rasmus Lema of the University of Aalborg, Xiaolan Fu of the University of Oxford) and Roberta Rabellotti of the University of Pavia describe a profound techno-economic paradigm transition which is under way towards a greener global economy. This opens up new opportunities for latecomer development, especially emerging economies. The authors recommend policies that are sensitive to the technological specificities of the different green sectors. They highlight alternative development pathways and call for countries to take active measures to enhance their technological capabilities and build open national and sectoral innovation systems through trade and investment policies and internationalization of R&D. The findings open up fresh perspectives also for other sectors, such as public health and digital infrastructure which are critical for building an inclusive society.

Tommaso Ciarli and several colleagues at UNU-MERIT, the University of Sussex Business School, the University of Lisbon, the University of Leiden, and University College London report on the misalignment between countries' research priorities and the SDGs and make policy suggestions accordingly. They suggest funders, donors and international organizations should seek steering research priorities towards SDG challenges that are also relevant to developing countries.

Mathieu Denis, David Kaplan, Katsia Paulavets, Anda Popovici and Anne-Sophie Stevance of the International Science Council call for transforming science systems to more effectively respond to 21st century global challenges. They note that the pandemic has highlighted deficiencies in the capacity of science systems to respond to new priorities in a timely manner while limiting the disruption to ongoing research. They put forward several recommendations aimed at governments, science funders and research institutions, including to strengthen the directionality of science and change its practice; to enhance communication of scientific knowledge, public understanding and trust in science; and to improve science-policy interfaces.

William Kelly of the World Federation of Engineering Organizations, the American Society of Civil Engineers, and the Scientific and Technological Community Major Group highlights the important role of engineering standards to protect public health, safety and the environment for the SDGs – a fact both policy makers and engineering community need to be aware of. He calls on the UN to take steps to protect the existing investments into the built environment under a changing climate. He also suggests the UN endorse the WFEO Model Code of Practice on Principles of Climate Change Adaptation for Engineers and encourage WFEO to maintain and update the Code as appropriate.

Tom Wakeford and Neth Dano of the ETC Group insist emerging frontier technology must adhere to Rio Principles for SDGs to work. They report on two experiments - gene drive mosquitoes in Burkina Faso (reducing malarial vectors), and a geoengineering experiment in Sweden (aerosol spraying in the stratosphere). Both were promoted to advance the SDGs, but in view of the authors put fundamental principles of sustainable development on the line, thus ultimately threatening the achievement of the SDGs.

Jonathan Tsuen Yip Wong and Tengfei Wang of ESCAP propose policy approaches to direct frontier technologies - such as AI, robotics, 3D printing, and the Internet of Things - towards inclusive and sustainable development in Asia and the Pacific. They propose that despite uncertainties over the scale and pace of the frontier technological transition, governments should put in place policies to be prepared.

Kibae Kim of the Korea Policy Center for the Fourth Industrial Revolution the new governance around data suggests principles for inclusive governance. He notes the complexities of re-balancing human dignity with financial benefits, thereby losing human beings' fundamental rights in the new economy. He recommends ensuring fair data, transparent algorithms, and trustworthy architecture.

Seven science-policy briefs on digitalization, AI and robotics

Kevin Mallinger, Alexander Schatten, Gerald Sendera, Markus Klemen, and A Min Tjoa at SBA Research, Austria, explore the potential threats of "human digital twins" for digital sovereignty and the SDGs. These twins are the aggregation of human related data that is supposed to represent its real counterpart in the virtual world. They note the manifold business opportunities on the hand and adverse sustainability impacts on the other and call for a new regulatory context for ethical digitalization.

Olivier Combe and Chantal Line Carpentier of UNCTAD and Tanya Smith of Blockchain Infrastructure Research discuss central bank digital currencies as the next step in the evolution after bitcoin and stable coins. They suggest central bank digital currencies to be regulated to be inclusive, secure, private, accessible and interoperable.

A team of robotics experts around Dominik Boesl of the Hochschule der Bayerischen Wirtschaft in Germany and several colleagues in Hungary, Canada, India and Belgium call for harnessing robotics to "automatize" the SDGs. They map the impacts – both positive and negative – of robotics on the achievement of the various dimensions of the SDGs. The call on the UN to provide specific targets for robotics and make several specific suggestions for international robotics institutions.

Taro Arikawa, Ikuo Sugiyama, Yoshikazu Nakajima, Hideaki Koizumi and Taikan Oki of the STI 2050 Committee of the Engineering Academy of Japan make suggestions for the future of urban design, in particular proposing multi-AI network city clusters and explore a roadmap to its implementation. The idea is to create a human-centered city; ensure human security and well-being; and to develop a system to autonomously manage an entire city with the cooperation of humans and AI by connecting diverse data between urban clusters.

A team around Jean-Martin Bauer and several colleagues at the World Food Programme reports on their experiences in supporting governments and communities with artificial intelligence and machine learning systems to improve disaster assessment in Mozambique and Lebanon. It outlines the lessons learned from preparedness efforts, such as prepositioning equipment and training, and the need for more robust data protocols, governance and collaboration to maximize the technology benefits.

A team at Wageningen University in the Netherlands shows how virtual reality tools can strengthen natural disaster preparedness, response and recovery by bridging the gap between knowledge and action. It presents a number of policy recommendations based on scenario analysis.

Edward Lorenz of Aalborg Business School in Denmark and Erika Kraemer-Mbula of the University of Johannesburg in South Africa report on lessons learned from a survey on adoption of new digital technologies in micro and small enterprises in South Africa. The results show that these enterprises do adopt new technologies, which can have a positive impact on their capacity to develop and implement new products, services and processes. They also report empirical results on key constraints related to financing, training and skills.

Three science-policy briefs on big Earth data, satellites and remote sensing

Ryuichi Maruyama and Michiharu Nakamura of the Japan Science and Technology Agency identify advanced sensing as core technology in all areas of the SDGs, providing many examples. They discuss latest developments in sensing technologies, in terms of enhancements in terms of modality, performance, usability and functions. They provide an overview of advanced sensing applications in international projects promoted by Japanese institutions. They identify challenges and recommend promotion of interdisciplinary research, clarification of rules for open use of data and data platforms, expanding international partnerships, and raising cyber-security literacy and awareness of data ethics associated with advanced measurement.

Huadong Guo of the International Research Center of Big Data for Sustainable Development Goals in China highlights the value of Big Earth data and suggests conducive policies to leave no-one behind, in terms of data policy (data quality and standards at scale), infrastructure, and international platforms for scientific cooperation. He suggests that for the SDGs to be successful, traditional barriers between institutions, countries and sectors that block the sharing of data, information, and knowledge would need to be removed. Big Earth Data can help integrating multi-source data and information for sustainable development.

The UN Office for Outer Space Affairs explores the drivers behind mega-constellations - a new rapidly emerging technology - and explore their impacts. They conclude that mega-constellations could amplify existing space benefits and tap new markets, especially in Earth observation and broadband, but that they also come with challenges to the safety, security, and sustainability of the space environment.

Ten science-policy briefs on environmentally compatible frontier technologies

Joshua Pearce of the Michigan Tech Open Sustainability Technology Lab describes how open hardware has enabled distributed recycling and additive manufacturing (DRAM), where post-consumer waste can be recycled in the home or community into valuable products for less than 1% of commercial costs and far superior environmental performance. Millions of free and open source hardware designs are now available to small business and consumers themselves. DRAM could greatly reduce the costs of reaching the SDGs by enabling people to make what they need in their communities from abundant waste materials.

Richard A. Roehrl of the UN Department of Economic and Social Affairs provides and analysis of the driving forces of rising energy demand for Internet applications and artificial intelligence, including entirely new services, fundamental limits to digital technology efficiencies, and much lower energy efficiencies of AI systems compared to human brains. He concludes that the most likely overall result will be accelerated, increased energy demand for the Internet and AI in the coming decades, unless sufficiency considerations and massive investments in end-use efficiencies fundamentally change the current direction.

Nicholas Harrison of the Carnegie Climate Governance initiative describes new technologies that are being explored to artificially cool the planet through solar radiation modification which faces multiple uncertainties and knowledge gaps with potentially serious implications for delivery of the SDGs. He provides an overview of the state of research and development, implications for the SDGs and the need to strengthen governance and ideas for possible pathways for closing knowledge and governance gaps in future.

A team at Wageningen University in the Netherlands reviews biomimicry to tackle air pollution in urban areas. They conclude that it is a cost-effective solution which can be applied in developed and developing countries alike. They also suggest potential pathways to make biomimicry more mainstream in education, investment and policymaking.

Another team at Wageningen University reviewed the use of robotics for monitoring marine ecosystems. The approach can make monitoring capacity more effective, efficient, and safe, but there is a need for support and accessibility, including from governments and international bodies. They also highlight the importance of data transparency and interdisciplinary, multi-stakeholder collaboration.

Son Bum Suk of the Green Technology Center in the Republic of Korea presents an energy-prosumers vision in which consumers of electricity also become producers and sellers of distributed, renewable electricity. He presents the technologies needed and discusses the SDG impacts.

Yet another team at Wageningen University explored pathways for 5G technology in irrigation to make it more effective, efficient, and sustainable. It suggests that barriers related to data and network governance, inclusive access and societal adoption need to be addressed and that close collaboration between the public and private sector is needed.

A team at the State University of New York, in the USA assess fast pyrolysis and conclude that it is a sustainable and clean method of energy production which has been made more accessible and efficient through ablative technologies and improved catalytic upgrading. Ablative pyrolysis reactors can convert plant material into bio-oils and biochar which can be used within the community for farming, cooking, or fuel, or sold for a profit. The use of mobile ablative pyrolysis units could provide further economic and social empowerment to low-income communities and women. However, further research is needed to reduce large initial financial investment needs.

Siddhant Bansal and Erin Morris of the State University of New York identify saltwater greenhouses as solutions for regions affected by food and water insecurity by allowing them to grow food using seawater/brackish water and sunlight. They describe benefits of and barriers to implementation of these systems.

A team at Van Lang University in Viet Nam reviews the role of new chemical technologies needed for the future of plastic recycling. It concludes that such technologies will be essential for achieving a circular economy. Using a case study of Ho Chi Minh City, the team emphasizes the role of governments, including for connecting relevant industries in the plastic supply chain. Separating solid waste at source will still be a goal for developing societies since it helps recover plastic better in both quality and quantity.

Four contributions reporting on specific solutions and updates on country experiences

The Flemish Institute for Technological Research (VITO) in Belgium provide two case studies of practical integrated technological solutions for the SDGs: Anaerobic Digestion by Combining Organic waste and Sewage (ANDICOS,) and CO_2 capture (from postponed, cyclic to negative emissions). They detail superior technical characteristics and SDG benefits.

Thomas Basikolo of ITU provides an update on their AI and Machine Learning in 5G Challenge. He also explains why artificial intelligence, machine learning and supporting standards are so important for 5G and future networks.

Xiaolan Fu and Elvis Korku Avenyo of the University of Oxford, Pervez Ghauri of the University of Birmingham, and Xiaoqiang Xing of the University of International Business & Economics in China present an update on “The Inclusive Digital Model” project which carries out research into a new business model that seeks to enable marginalized people in developing countries to generate income and empower themselves by sharing their skills and experiences using a digital platform. They draw lessons from the ‘Kuaishou’ digital platform in China and the ‘Haate Haat’ digital platform in Bangladesh.

An overview of findings and recommendations of related UN flagship publications together with an external discussant perspective

The findings and recommendations on the impacts of new and emerging technologies were compared and contrasted for several UN reports, including UNIDO's Industrial Development Report 2020, ILO's World Employment and Social Outlook 2021, UNCTAD's Technology Innovation Report 2021, ITU/UNESCO’s Broadband Commission for Sustainable Development's State of Broadband Report 2020 and ESCWA's Big Data for Good: Can Big Data Illustrate the Challenges Facing Syrian Refugees in Lebanon. There is broad agreement among these reports that frontier technologies are creating deep economic, social and environmental impacts which could be long lasting and could disadvantage those communities, workers, firms, sectors and countries that do not have the infrastructure, skills and access to the technologies needed to be able to benefit from them. They also agree that the global community can, and should, take actions to moderate the negative impacts.

B. The big picture- science and technology policy issues

Latecomer Development in The Global Green Economy

Rasmus Lema (University of Aalborg); Xiaolan Fu (University of Oxford); Roberta Rabellotti (University of Pavia)

Abstract

A worldwide and profound techno-economic paradigm transition is currently under way: this is the restructuring towards a greener global economy, which has important implications for latecomer development. More so than earlier, transition is driven by deliberate changes in polices, strategies and institutions. These changes may create 'green windows of opportunity' because mission-guided technical change and market development influence the conditions for economic development. In this research we draw on insights from China, exploring how opportunities emerge and vary in different renewable energy sectors. We highlight the important role emerging economies may attain in the green transformation itself and distill implications for policy.

Until recently, the idea of green growth was limited to advanced economies while developing countries were reluctant to take up the challenge of sustainability. But today the dichotomy between green transformation and latecomer development has been turned on its head. The 'clean up later' model is being replaced by a leapfrog strategy, which offers alternative ways to bypass the high pollution models of growth. Countries such as China, India, Brazil and South Africa are not only reacting to the paradigm change but also actively contributing to the green transformation, adopting environmental policies and supporting the emergence of domestic sustainability-oriented industries.

There is increasing recognition that policies aimed at meeting environmental targets may be opening new economic development paths. The green transformation and the related techno-economic paradigm changes across institutional, market and technological domains, are opening windows of opportunity for the emerging economies to achieve leadership in new sustainability-related industries. In a recent article (Lema et al, 2020) highlight the importance of institutional transformations in the creation of new opportunities for economic structural changes associated with the green economy. Green Windows of Opportunity (GWO) represent a set of favorable, temporary conditions for long-run latecomer catch-up in sectors central to the green economy, which are markedly different from the windows of opportunity occurring in traditional sectors, mainly dealing with private, rather with public goods.

This article is based on quantitative and qualitative empirical evidence, collected in a Special Section "Green Windows of Opportunity: Latecomer Development in the Age of Transformation Towards Sustainability" on various green energy sectors - biomass, hydro, solar photovoltaic (PV), concentrated solar power (CSP) and wind - and on one emerging economy, China, which is moving rapidly towards leadership in several green technologies.

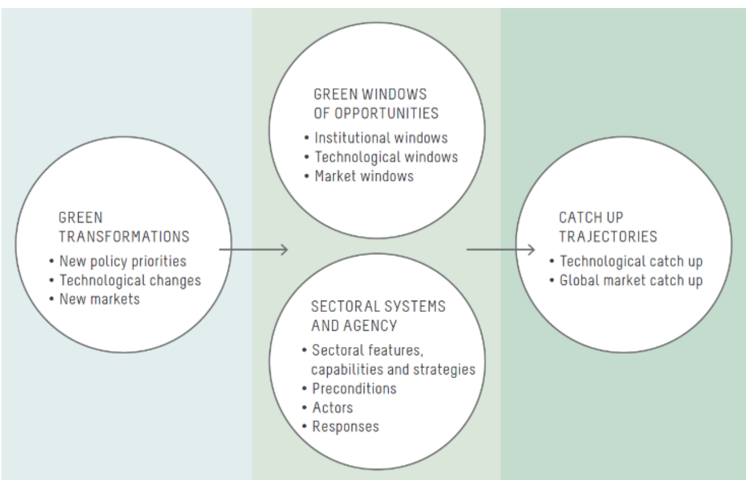
The research is guided by three high-level questions: (1) Is the green transformation opening new latecomer development opportunities? (2) What are the conditions and dynamics of green latecomer development? (3) Do we need a new conceptual framework to understand the determinants of changes in green industry leadership?

We believe there is a need for a new framework for two main reasons. First, it is essential to deviate from the environmentally unfriendly pathways paved by the advanced economies of North America and Western Europe. This makes catching-up frameworks and strategies, rooted in borrowed technologies and imitation, obsolete. Emerging economies should from the outset 'develop differently' rather than catch-up along established pathways (Altenburg, 2021). Second, the green transformation, as a significant driver of current capitalist development, has features that sets it apart from earlier paradigm changes. It is the first economic revolution which has a deadline, and it is steered explicitly by public policy, not only driven by economic utility functions but also by social value.

Green Windows of Opportunity

The analytical framework is summarized in Figure 1, with at its core Green Windows of Opportunity driven by institution-cum-policy changes rather than by modifications in technologies or markets. The evidence provided by our case studies shows that institutional changes are the central drivers of GWOs, which are favorable but time-bound conditions for latecomer development. Examples of GWOs in China include both cross-cutting changes such as the implementation of the 2006 Renewable Energy Law and sector-focused missions such as the Golden Sun Demonstration Programs implemented in the solar PV sector. While the root-causes of window emergence are essentially institutional and policy-driven in nature, they influence and interact with technological and market transformations. For example, mission-oriented policies in the solar industry resulted in induced technological change through the guidance of research and development activities as well as in significant demand creation through incentive changes, demand subsidies and public procurement.

Figure 1: The analytical framework: green windows of opportunity and catch-up trajectories



Firms and other sectoral system actors

The transformation of GWOs into upgrading and international competitiveness is not given or automatic and there is significant variability in catch-up trajectories at the sectoral level. The extent and nature of the actions of firms and other public and private actors in the sectoral system determine whether and how potential opportunities are translated into reality. Furthermore, technological maturity and tradability of green technologies also significantly affect sectoral trajectories. Catching-up is easier in technologically mature sectors characterized by tradable knowledge and standardized products, rather than in sectors with short technology cycles.

At firm level, the initial response is to acquire the basic production capabilities available globally to exploit GWOs. In mature sectors, it is relatively easy to acquire world-class technologies and market success depends on capital investments and organizational capabilities. For example, after the introduction of the 2006 Renewable Energy Law in China entrepreneurial activity in the biomass and wind sectors was enabled by the licensing of core technologies and production plant designs mainly from European firms (Dai et al., 2020; Hansen & Hansen, 2020).

But the different cases also show that for technological capabilities upgrading and deepening it is required a change of gear in relation to several components in the sectoral environment. For example, in the hydro energy industry, the increasing role of public R&D is evident in the repositioning of Chinese universities from the periphery to the core in patent citation networks, occurred in the last ten years, which, in turn, has led to the 'greening' of the sector and to increased reliability and efficiency of generators (Landini et al, 2020; Zhou et al., 2020). Sectoral innovation systems have also been reinforced by more intense interactions among lead firms, suppliers, technology providers and financial institutions. For instance, in solar PV, this type of responsiveness within the domestic sectoral system was key to the technological development of the sector after the contraction in the global market (Binz et al., 2020).

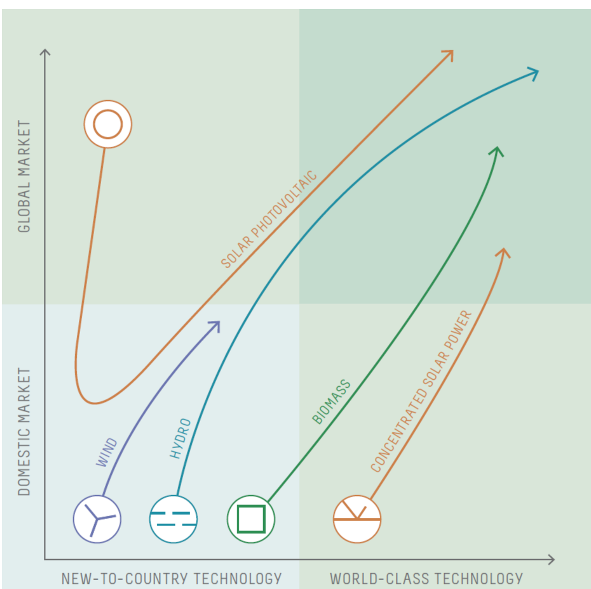
Conversely, in still evolving technologies, such as wind, the inability of the system to progress from technology absorption and domestic deployment to technological leadership in the global market results in domestic firms failing to achieve market leadership. Hain et al. (2020) propose the idea of a market trap where latecomers remain in a follower position and catch-up is aborted. It remains to be seen whether Chinese firms can leverage complementary capabilities in adjacent sectors to integrate advanced software capabilities and make inroads in the 'post-turbine technology regime' (Dai et al., 2020).

The above discussion indicates that to allow exploitation of GWOs, the sectoral innovation system must be dynamic and adapt continuously to different sector specificities and changing market and technological opportunities. Also, policies need to be tailored to the particular stage of catch-up and take account of sectoral specificities.

Green latecomer catch-up trajectories

Catch up refers to successful attainment of leadership by latecomer firms which shifts the balance of economic power between incumbents and latecomers. *Market catch-up* refers to the acquisition of increasing national and international market shares. In renewable energy sectors, this can be quantified as the share of energy generation capacity (in megawatts) sold in the domestic and global market. *Technological catch-up,* distinguishing between *new-to-the-country technology* and *world class technology*, is defined as the strengthening of technological capabilities relative to competitors and it can be measured with quantitative information (e.g., patent numbers and quality) or qualitative assessments of the 'distance' to the global knowledge frontier in a given sector. Discriminating between the market and technology dimensions it is possible to chart some trajectories of China's green sectors, depicted in Figure 2.

Figure 2: Latecomer catch-up in five green sectors in China



From domestic imitation to global leadership: this is the path followed by the hydropower and biomass sectors, which progressed from new-to-the-country to world-class technology.

Learning from exporting, over domestic strengthening, to global leadership: this is the trajectory of solar PV, starting from initial export of new-to-the-country technologies introduced in China by returnee entrepreneurs, to a focus on domestic market and technological upgrading, and finally to achievement of world-class technology, reinterring the global market (Binz et al., 2020).

World-class technology with limited global market progression: this applies to CSP, which, after upgrading to world-class technology, experienced little further market development (Gosens et al., 2020).

Domestic imitation with limited global progression: this pertains to wind upgrading to new-to-the-country technology in the domestic market, facing constrains in further development (Dai et al., 2020).

Policy implications

We have shown how the mounting techno-economic paradigm shift towards a more environmentally sustainable economy has opened GWOs for latecomer development in key green energy industries in China. Four policy implications are particularly important.

1. There are important opportunities for latecomer development in emerging economies engaging in the pursuit of green transformation. Policy makers need to deliberately bring together, otherwise distinct, policy domains. Environmental and energy policies are critical for the emergence of GWOs, based on their domestic deployment and market creation effects. At the same time, industrial and innovation policies are also important to promote firm and system level capabilities to respond to opportunities. There is a need to consciously co-design policies across these domains for dynamic synergies to arise.
2. Policies need to be sensitive to the technological specificities of the different green sectors. There are different roles to be played by governments and innovation system actors depending on factors such as the maturity of technology and capital intensiveness. Different designs are needed along key policy dimensions such as R&D investments, global knowledge acquisition, national promotion of diffusion between enterprises and infant industry support.
3. GWOs can be exploited by both developed and developing economies. Countries that take active measures to enhance their technological capabilities and build open national and sectoral innovation systems through trade and investment policies and internationalization of R&D, may achieve faster catch-up and, even, leadership. The emergence of latecomer countries in the green economy has an internationally beneficial effect by reducing the price of energy transition technologies and enabling more appropriate technologies. This facilitates mobilization of finance and technology

for more affordable green energy systems in the global South.

4. Our findings open up fresh perspectives also for other sectors, such as public health and digital infrastructure, critical for building an inclusive society. In a closely inter-connected and globalized world, there is a collective interest in enhancing international technological and productive capability in vaccines and medicines and in digital infrastructure. Policy coordination and the efforts of the global community in ensuring equal access and responsible provision of global public goods, could create 'global challenge-led windows of opportunity'. The global community should facilitate and support changes of leadership in these sectors through engagement, collaboration and regulation-based supervision to ensure equal access to high quality, economically affordable and technologically appropriate products and services.

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Research priorities may not align with the SDGs: policy suggestions to steer them

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Abstract

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. Such unequal distribution of research efforts may be of little support to the SDGs. We show that countries' research priorities do not always align with their SDG challenges, which may hinder their capabilities to address them. 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.

An uneven distribution of science and innovation may not support the SDGs

It is well known that most academic research is produced in high-income countries[1]. These are also the countries that rank highest in relation to the SDG targets (if we exclude SDGs 12 and 13).

Figure 1 maps the number of publications per capita across countries between 2001 and 2019 (top panel) and their SDG Index 2020 (bottom panel). The figure illustrates that most research is published in countries that face the smallest SDG challenges. Not surprisingly, the correlation between research output per capita and a country's ability to achieve the SDGs is positive (Figure A1).

What is the likelihood that such a large amount of research published in a few high-income countries, which nurture emerging technologies, will addresses the SDGs challenges of lower-income countries[2]? If they do, what is the likelihood that this research aligns with their national and local SDG and research priorities[3]? In the longer term, to what extent can reliance on foreign research contribute to building research capabilities in low-income countries, which may allow them to prioritise national and local SDGs priorities[4–8]?

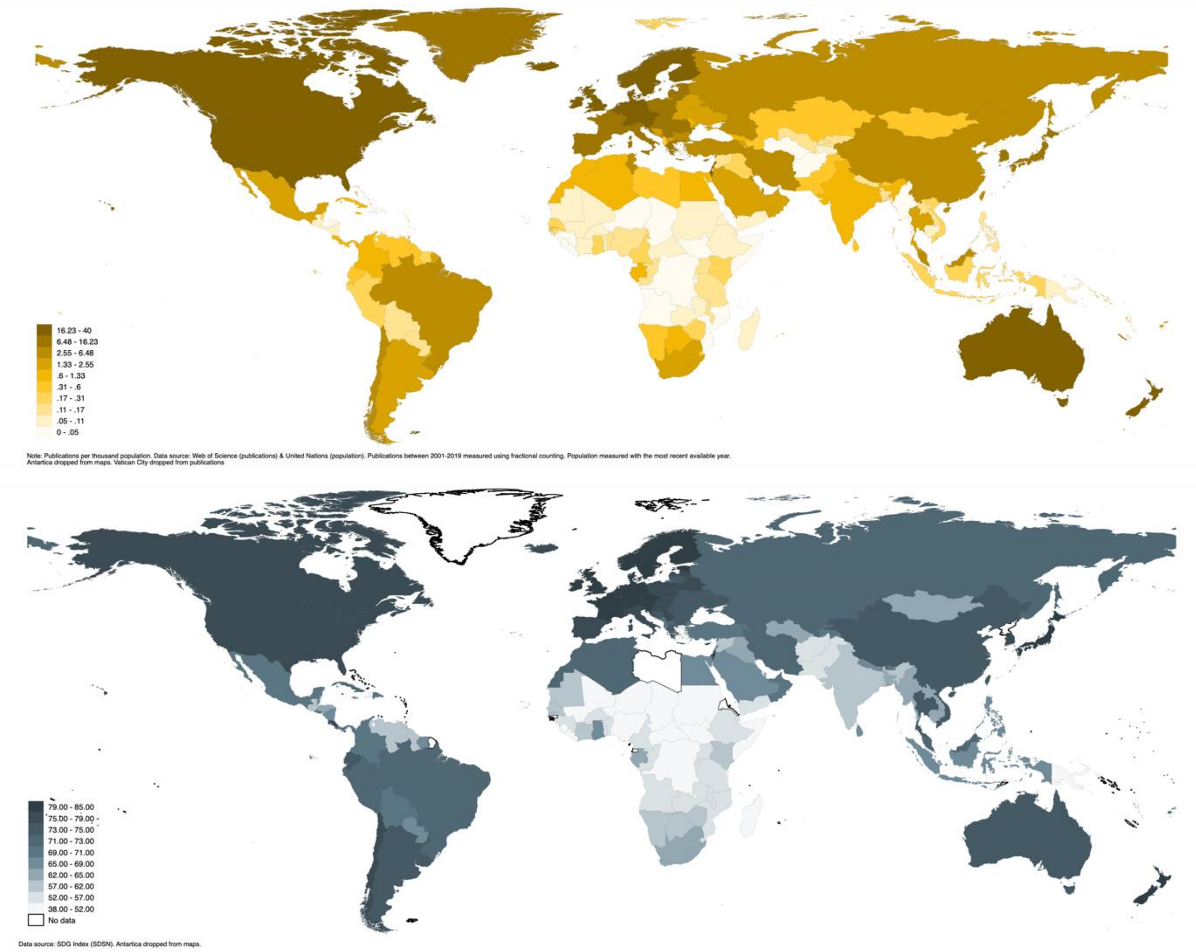
Science and technology can contribute to addressing (and creating) societal challenges like those set out in the SDGs[9], but scientific efforts are unevenly distributed with respect to the societal challenges they seek to address and they engender[10]. While it is likely that different challenges need a different amount and type of research, it is not obvious why the challenges of those most in need tend to be the least prioritised in research funding[11–13].

In the context of the Global Goals, these least prioritised challenges are likely to coincide with the SDG targets. Examples include: health – where research efforts do not prioritise diseases that are more common in low-income countries[14,15]; agriculture – where research specialisation is only partially aligned with country priorities[16]; and the global production process – that focuses on the consumption patterns of the wealthiest rather than on global social needs[17]. Such imbalances are not solely driven by the economic incentives of private companies, they are also observed in publicly funded research[18], despite the differing mission of public funders.

It has been argued that inequalities are an obstacle to achieving SDGs[19,20]. Such inequalities in research prioritisation may reproduce those inequalities[21–23], making it even harder to address the SDGs. The observed concentration of research in few countries and organizations is a challenge to reduce such inequalities, as low-income countries may need to rely on funder's and donors' capabilities and research agendas.

One possible way, perhaps over-simplistic, to break this vicious cycle, and improve science and innovation's contributions to the SDGs, is to better align research priorities to national and local SDG challenges[24,25].

Figure 1: Publications and the SDG Index



***Notes**. Top panel: number of publications per capita (using fractional counting for publications co-authored across different countries). Bottom panel: SDG Index 2020.*

Do countries' research priorities align with their SDG challenges?

In the STRINGS (Steering Research and Innovation for Global Goals) project, we analysed countries' research priorities in relation to SDGs since the launch of the UN 2030 Agenda (2015-2019), and whether this prioritisation aligns with their greatest SDG challenges.

To measure countries' research priorities in relation to SDGs we use a relative specialisation index (Balassa) computed using publication data from the Web of Science (WoS). Using the Balassa index, a country is considered to prioritise research related to a given SDG if their research portfolio includes more publications related to this SDG than the world average.

To assign scientific publications to a specific SDG, we first built a query with a set of terms strongly associated with the SDG based on searches and text-mining techniques on a wide array of policy reports, grey literature, scientific publications, web forums and official UN sources[26]; we then used those SDG-related queries to search publications in 4013 research areas that are generated by citation relations between all WoS publications[27]. In this way we reduce the limitations of focussing on a specific set of keywords[28], and include scientific publications that contribute to SDG-related research even when not using SDG specific language.

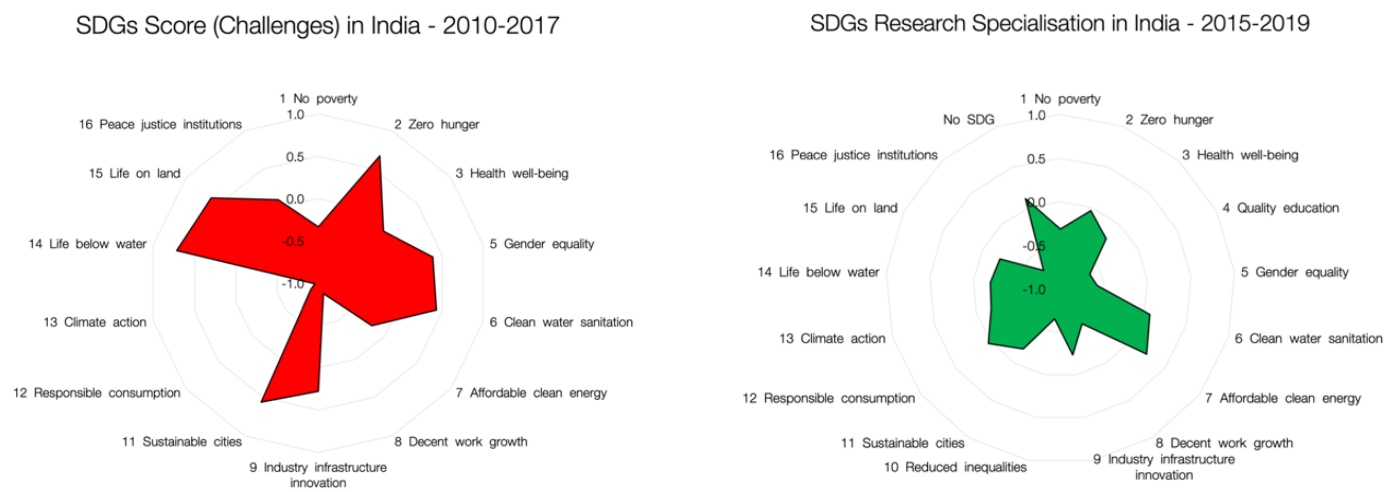
To measure the salience of SDGs across countries, we built an index per SDG that combines SDG target indicators from the UN SDG database and the SDSN SDG Index. For each indicator we compute the distance with respect to countries that are closer to meeting the SDG target. We then computed a country-SDG index normalised between -1 and 1 using principal component analysis. A value closer to 1 indicates that the country is facing a relatively higher challenge with respect to the SDG.

Figure 2 and Figure 3 provide two different examples, from India and Ethiopia. Figure 2 panel (a) plots the main challenges in India between 2010-2017, in relation to other countries. These are SDG 2 (zero hunger), SDG 5 (gender equality), SDG 6 (clean water and sanitation), SDG 9 (industry, infrastructure and innovation), SDG 11 (sustainable cities), SDG 14 (life below water) and SDG 15 (life on land). Figure 2 panel (b) plots the areas in which Indian researchers are specialised, in relation to other countries: SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy) and SDG 12 (responsible consumption and production). At a country level, since 2015, India seems to be focussing on building research capabilities only related to one major challenge, SDG 6.

Figure 3 plots the main challenges (a) and research priorities (b) for Ethiopia. In this case, results suggest that the country is building research capabilities in all its main SDG challenges, with the exception of SDG 7 (affordable and clean energy).

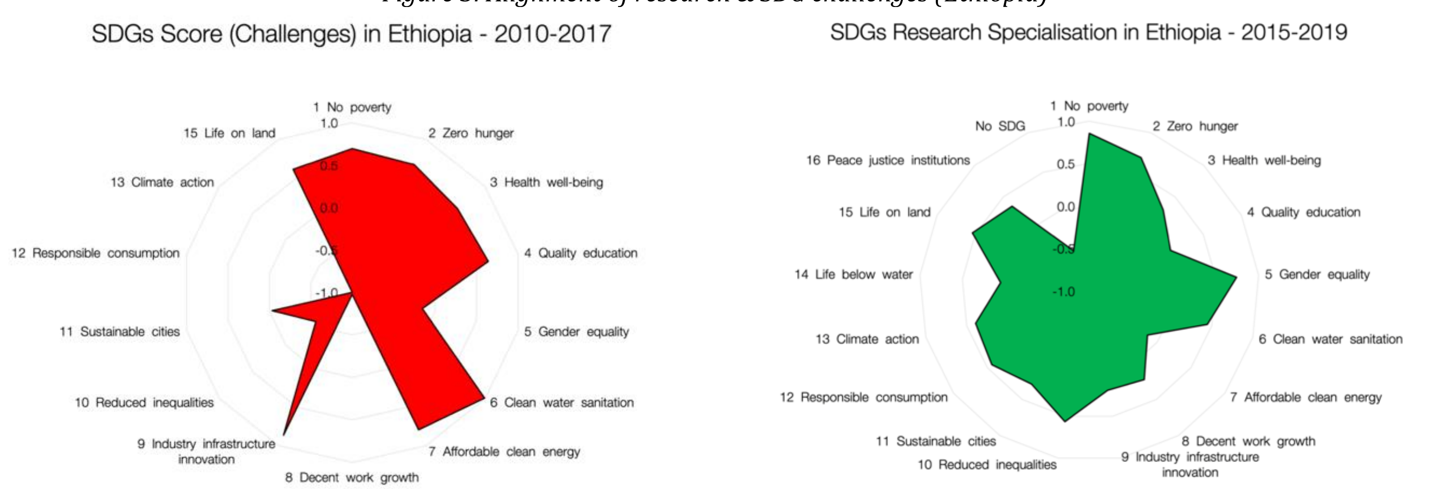
We tested the relation between research priorities (2015-2019) and SDG challenges (2008-2017) across all countries, for all SDGs. Table 1 reports the pairwise correlation, suggesting that countries facing a major challenge in relation to SDGs 1 (no poverty), 2 (zero hunger), 3 (good health and well-being), and 6 (clean water and sanitation), tend to prioritise research on those SDGs. This is, for example, the case for research in agriculture (SDG2) and health (SDG3), where historically low-income countries tend to focus their research efforts, in collaboration with foreign funders (Figures 2A and 3A).

Figure 2: Alignment of research & SDG challenges (India)



(a) (b)

Figure 3: Alignment of research & SDG challenges (Ethiopia)



(a) (b)

Table 1: Pairwise correlation of SDG challenges (2008-2017) versus SDG research priorities (2015-2019) in all SDGs

	Score_SDG1	Score_SDG2	Score_SDG3	Score_SDG4	Score_SDG5	Score_SDG6	Score_SDG7	Score_SDG8	Score_SDG9	Score_SDG10	Score_SDG11	Score_SDG12	Score_SDG13	Score_SDG14	Score_SDG15	Score_SDG16
Research specialisation SDG1	0.65	0.71	0.59	0.08	0.63	0.56	-0.32	0.16	0.07	0.43	0.28	0.37	0.45	0.23	0.49	0.35
Research specialisation SDG2	0.49	0.60	0.28	-0.01	0.43	0.67	-0.04	0.07	0.03	0.21	0.26	0.39	0.36	0.17	0.36	0.16
Research specialisation SDG3	0.52	0.64	0.36	-0.05	0.46	0.61	-0.22	0.08	-0.04	0.26	0.16	0.31	0.34	0.16	0.40	0.23
Research specialisation SDG4	0.36	0.57	0.30	-0.27	0.31	0.57	-0.12	-0.08	-0.10	0.04	0.06	0.24	0.24	0.06	0.25	-0.01
Research specialisation SDG5	-0.24	-0.06	-0.09	-0.33	-0.20	0.22	0.30	-0.33	-0.17	-0.39	-0.07	-0.03	-0.32	-0.34	-0.39	-0.43
Research specialisation SDG6	0.56	0.70	0.42	-0.08	0.48	0.64	-0.26	0.08	-0.03	0.28	0.20	0.35	0.44	0.25	0.50	0.21
Research specialisation SDG7	0.69	0.74	0.56	0.12	0.66	0.60	-0.29	0.28	0.13	0.49	0.34	0.42	0.53	0.35	0.57	0.41
Research specialisation SDG8	-0.49	-0.54	-0.27	0.10	-0.37	-0.47	0.20	-0.09	-0.01	-0.26	-0.13	-0.28	-0.30	-0.14	-0.39	-0.18
Research specialisation SDG9	0.35	0.55	0.04	-0.02	0.24	0.59	-0.12	0.06	-0.05	0.09	0.17	0.22	0.39	0.23	0.37	0.08
Research specialisation SDG10	0.40	0.55	0.28	0.20	0.31	0.47	-0.15	0.12	0.00	0.23	0.10	0.27	0.48	0.44	0.50	0.21
Research specialisation SDG11	0.32	0.46	0.29	-0.22	0.28	0.52	-0.08	-0.07	-0.07	0.06	0.15	0.21	0.14	-0.01	0.17	-0.01
Research specialisation SDG12	-0.50	-0.61	-0.34	0.13	-0.42	-0.51	0.21	-0.06	0.02	-0.22	-0.14	-0.32	-0.31	-0.14	-0.37	-0.17
Research specialisation SDG13	-0.39	-0.60	-0.26	0.18	-0.30	-0.51	0.23	0.02	0.10	-0.11	-0.03	-0.26	-0.30	-0.16	-0.40	-0.07
Research specialisation SDG14	0.02	0.14	-0.20	-0.13	-0.10	0.37	0.14	-0.16	-0.15	-0.20	-0.03	0.03	-0.01	-0.02	-0.02	-0.24
Research specialisation SDG15	-0.10	-0.02	-0.20	-0.25	-0.07	0.14	0.12	-0.34	-0.39	-0.23	-0.19	-0.18	-0.15	-0.14	-0.16	-0.16
Research specialisation SDG16	0.29	0.45	0.02	-0.19	0.07	0.48	-0.11	-0.12	-0.18	-0.07	-0.08	0.14	0.26	0.23	0.35	-0.09

However, for all other SDGs, the correlation is either zero or negative. This suggests that countries facing challenges in relation to, for example, education, gender equality, access to energy, responsible consumption and production, and climate action, do not prioritise research that addresses those challenges. This is, for example, the case of SDGs 12 and 13, where high-income countries, which are also the major polluters, do not prioritise research to address these challenges (Figures 4A and 5A).

Policy recommendations

Research on emerging technologies opens great opportunities and challenges. How can we steer research priorities so that both opportunities and challenges prioritise global, national and local SDG priorities across low-income countries?

There are several factors that explain why research prioritisation is less aligned with the societal challenges of the people who are most in need.

R&D priorities emerge as the outcome of the interaction of several, competing and related actors[29], technologies[30], socio-economic conditions[31,32], politics[33] and science communities[34].

SDGs are also a complex system, constituted by a large set of targets that relate in positive and negative ways[35,36]. This is at odds with research, which instead advances mainly through specialisation[37,38].

Research and SDG priorities are both global and local, and they differ at multiple levels. Different stakeholders, policy makers, users, citizens and scientists hold different views on which research and SDG targets to prioritise, in which area, and how[39,40]. Those actors differ substantially in their power to influence research funding[41,42] and different societal groups are unequally (or not at all) represented in research funding decision making[43,44]. Path dependency also provides a strong advantage to incumbent technologies and research trajectories[45,46].

Research evaluation tend to focus on a narrow understanding of research excellence and productivity (DORA), rather than on its impacts on societies[47,48] partly because due to the above complexities these are not straightforward to assess.

Here, the STRINGS report will provide evidence and policies to orient research and innovation towards the SDGs, across different contexts.

The above factors suggest a number of opportunities for funders, donors and international organisations to steer research towards the SDGs.

Prioritisation needs to reflect the views of different communities across different contexts, especially those that may benefit from or suffer the negative consequences of research and innovation. For instance, in STRINGS we are running a large Delphi survey across contexts and stakeholders, to capture the breadth of views on what research and innovation areas may contribute to SDGs in the future. Such exercises could be done in a systematic way at different levels.

Research funders may need to prioritise open and transdisciplinary research to maximise impact on the SDGs (Arza and Colonna, 2020), which also requires a different system of incentives for researchers and research evaluation[49]. This should also improve our understanding of the synergies and trade-offs between different research trajectories.

Funding may need to consider the role of research in generating capabilities for local actors to address challenges, and how it relates to existing, often not well mapped knowledge[50], rather than focusing exclusively on the cure to the challenges (Chataway and Ciarli, 2020).

Policy needs to facilitate plural perspectives and pathways[51] in steering research towards the SDGs. It should recognise and nurture the multiple ways in which different perspectives characterise the SDGs and what research is closely related to them, in positive and negative ways (Ràfols, 2020), and which direction should be prioritised. Rigorous, transparent and more democratic global, national and local dialogue between different interest groups and stakeholders is central to aligning research priorities with challenges (Arora and Stirling, 2021).

All the above suggests that policymakers do not have an easy task to improve how research is prioritised to better contribute to the SDGs. But complexity is a feature of both the research and the SDGs systems, and should be taken on board, better understood, and leveraged, rather than oversimplified[52]. "The link between knowledge and action is not automatic, and needs to be cultivated, supported and steered to where it is most needed. Science can inform policy, but policies can (and should) direct science towards the greater (and more equal) good" (Assa, 2020).

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Annex: additional figures

Figure 1A: Relation between publication and the SDG index

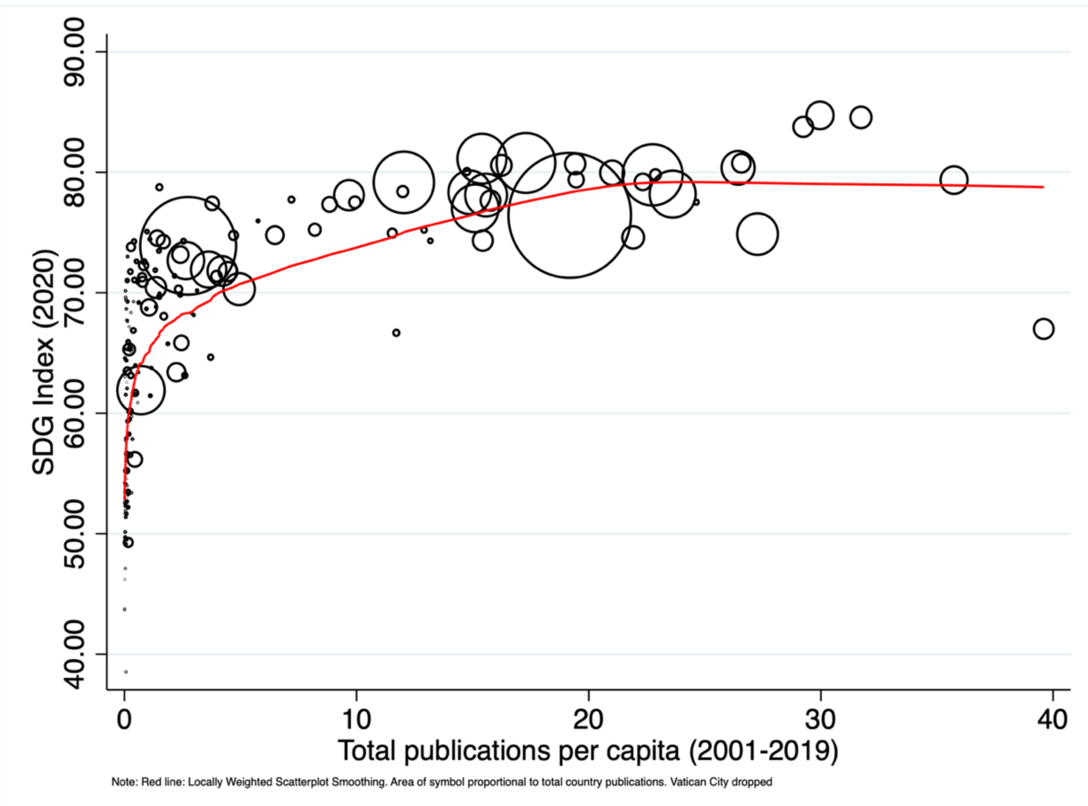


Figure 2A: Relation between the severity of the challenges and research specialisation (SDG2)

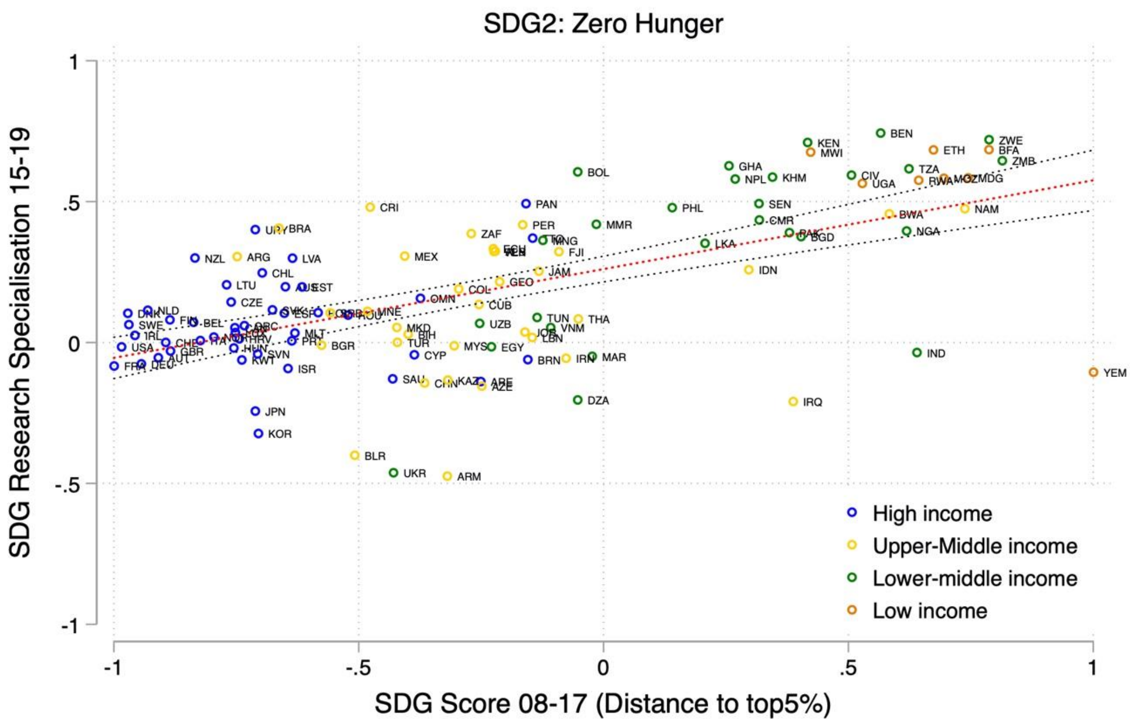


Figure 3A: Relation between the severity of the challenges and research specialisation (SDG3)

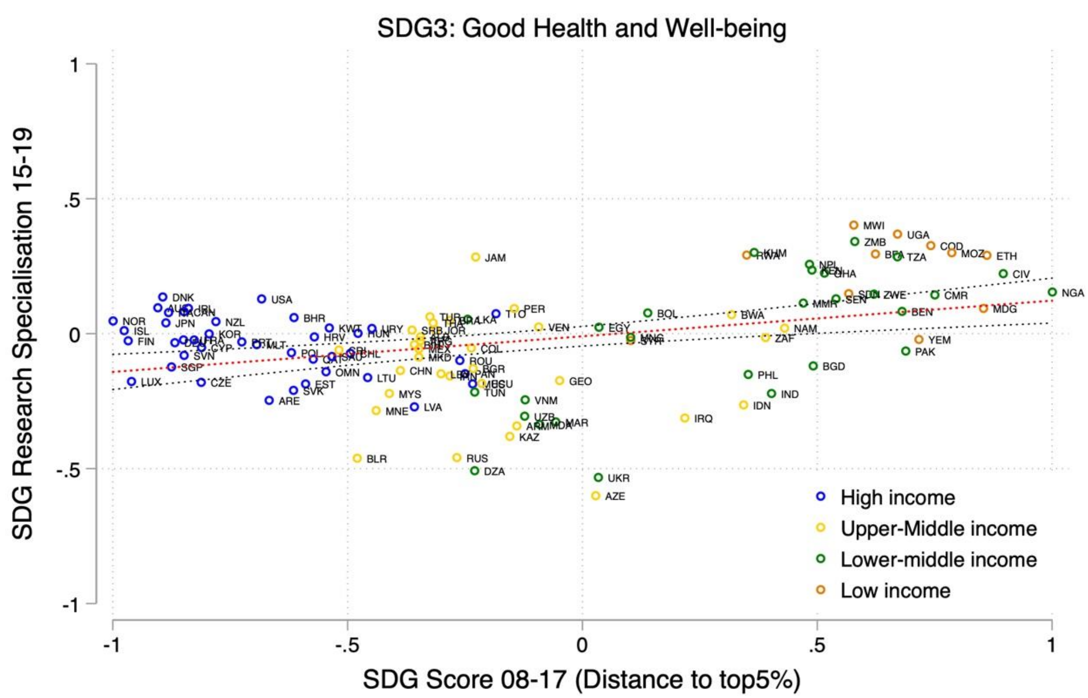


Figure 4A: Relation between the severity of the challenges and research specialisation (SDG12)

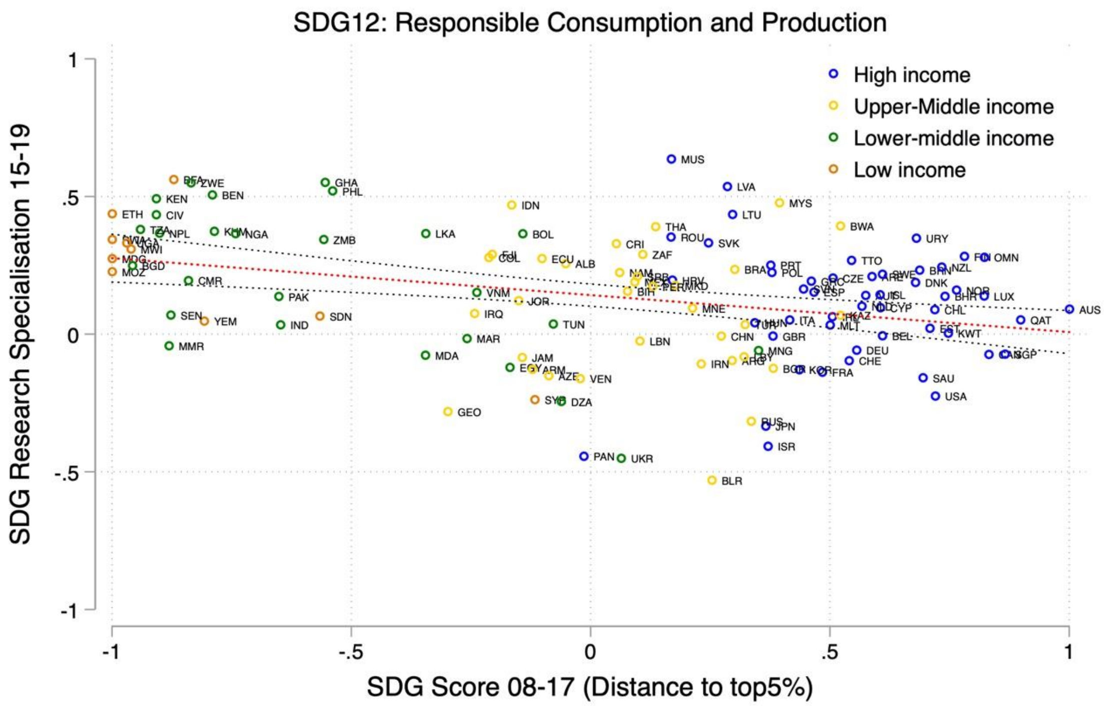
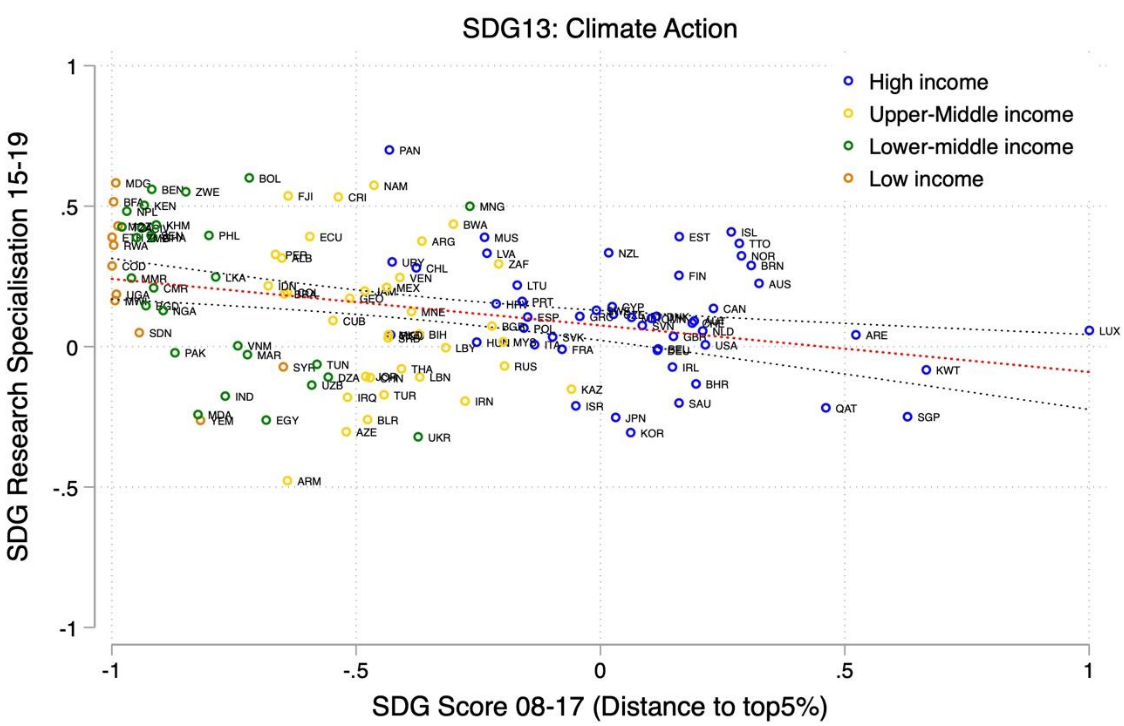


Figure 5A: Relation between the severity of the challenges and research specialisation (SDG13)



Transforming science systems to effectively respond to 21st century global challenges

Mathieu Denis, David Kaplan, Katsia Paulavets, Anda Popovici and Anne-Sophie Stevance (International Science Council)

Abstract

Scientific communities worldwide are actively responding to COVID-19 and its consequences. However, the pandemic also revealed deficiencies in the scientific research environment related to 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. We must transform science systems to enhance their capacity to address 21st century challenges. This report puts forward a set of recommendations aimed at governments, science funders and research institutions, across four areas: strengthening the directionality of science; changing the practice of science; enhancing communication of scientific knowledge, public understanding and trust in science; and improving science-policy interfaces at all levels of governance.

The COVID-19 pandemic has put science under the spotlight and has stimulated strong public interest in and enthusiasm for science (The Lancet 2020). Scientific communities have been mobilized by governments worldwide to generate insights on a wide range of issues – from advances in epidemiology, clinical care, identifying treatments and developing vaccines to investigating underlying causes of the pandemic and its socio-economic impacts – and to shaping response strategies that would take account of the multidimensional nature of the crisis. However, the pandemic has also amplified and brought to the surface deficiencies in the scientific research environment. These include the lack of a system of recognizing and rewarding the contributions made by researchers to addressing an urgent crisis; persistent inequalities in science, with female scientists and scientists with young children being the most impacted (Myers et al., 2020); limitations of scientific publishing and the current peer-review system which constitute an obstacle for the wide and accelerated dissemination of knowledge, and deficiencies in the communication of scientific knowledge, which contributes to limited public understanding and trust in science. There is currently very little emphasis on the communication of scientific findings and effective communication receives little recognition in the research evaluation system (Rovenskaya E. et al. 2021).

Addressing these limitations to the science system will be essential to enhance its functioning in general, and particularly at times of future crises. Science systems need to be strengthened to be able to generate the knowledge necessary to support and steer transformational changes towards a sustainable and equitable world. This involves enhancing the capacity of science to contribute to building resilience to future shocks. Addressing disasters effectively requires a much stronger emphasis on addressing the underlying root causes of risks that are the result of within socio-economic development systems. As captured in the Sendai Framework for Disaster Risk Reduction, the global agreement to “reduce and prevent disaster risks across the globe”, science plays a critical role in building resilience by identifying the key drivers of risk and their implications for risk management; by informing prevention and mitigation strategies; by supporting the development and implementation of appropriate preparedness and effective response to disasters; by generating the knowledge necessary to understand the interconnected nature of risk in an ever-riskier world which has seen an increase in the frequency and magnitude of extreme weather and climate events in the past years; these events and slow-onset processes linked to environmental degradation threaten to erode the social and environmental foundations indispensable to the prosperity, development and well-being of humanity.

The COVID-19 pandemic is a timely reminder of how hazards within the complex and changing global risk landscape can affect lives, livelihoods and health. It provides a compelling case for an all- hazards approach to achieve risk reduction as a basis for sustainable development. The broad range of hazards of relevance to risk reduction and resilience building, and the increasingly interconnected, cascading and complex nature of natural and human-induced hazards, including their potential impact on health, social, economic, financial, political and other systems, are all interlinked in the discussions on sustainable development and climate change adaptation.

The broad range and complex nature of hazards requires a systematic approach and standardized characterization of hazards for countries to be able to assess and accordingly enhance their risk reduction policies and operational risk management practices. To address this major gap, the ISC and the United Nations Office for Disaster Risk Reduction launched the Sendai Hazard Definition and Classification Review Technical Report aimed at identifying the full scope of all hazards relevant to the Sendai Framework and the scientific definitions of these hazards.

In addition, as extreme events such as floods, droughts are on the rise as a result of climate change and disasters such as the COVID-19 pandemic have the potential to reverse development trends, there is an urgency to better understand how risks are interlinked by bringing together knowledge from across the natural and social sciences, as well as practice. In particular, better metrics, models and tools are needed to understand the cascades of extreme events and vulnerabilities as the domino effects of these complex dynamics are currently not well addressed in SDG strategies (Reichstein M. et al., 2021). Global efforts within the scientific and policy communities need to be much more robust to the changing and interconnected nature of risk in a warming world.

To address today's sustainability challenges and accelerate transformations, multifaceted and integrated approaches across disciplines are needed (Aldrich, 2014; Ledford, 2015). In addition, to be more impactful and usable in policy, the scientific community must better connect and work with governments, practice communities and other stakeholders (Wowk K. 2017). Science systems must advance and reward collaborative, open, diverse, inclusive approaches. Scientific research also needs to go beyond producing knowledge about the state of the world and associated challenges to generating knowledge and identifying solutions to the world's biggest challenges. Science needs to increasingly become a driver of change.

We identify a series of specific actions to increase the ability of science systems to better respond to sustainability challenges and foster transformations toward a sustainable and resilient future for all:

Strengthening the directionality of science through mission-oriented research and strategic cooperation

Solving contemporary global challenges requires strengthening the directionality of scientific enterprise to achieve wider social and policy goals. The SDGs, adopted by 193 countries, offer a shared compass for concrete action, which can be turned into concrete, measurable, and achievable missions for science (Mazzucato M. 2018). In addition, building future resilience is another 'high-level' purpose and complex challenge requiring a more specific focus through mission-oriented research and strategic cooperation.

The global landscape of actors in research and other domains working on the SDGs is crowded and fragmented, undermining the effectiveness of the different efforts and threatening the attainment of the SDGs. A more coordinated and strategic approach to scientific research and science funding is required to ensure that different efforts, very often situated at national level, are connected and coordinated to contribute collectively and effectively to specific global goals. Global multilateral scientific cooperation is urgently needed, at scale and in a timeous manner.

To accelerate the impact of science, enhanced collaboration between national science funders, foundations, the private sector and donors is crucial. The COVID-19 pandemic has demonstrated that such collaboration is critically needed and, more importantly, has demonstrated important instances of enhanced collaboration. To ensure coordination, science funders need to overcome divergent agendas and interests and better combine their efforts in working towards achieving common goals. To this end, more transparent practices on the part of science funders will be required. This should include open sharing of data, funding calls, research assessments and policies. Funding models for international research collaboration that employ the same funding procedures for all research partners, rather than multiple national funding arrangements, would facilitate and accelerate research on SDGs globally.

Increase transdisciplinary research and advance open science

The pressing and complex global sustainability issues require interdisciplinary and transdisciplinary research approaches to better understand their multiple underlying drivers, interdependencies and complexities (Mauser W. et al. 2013). While transdisciplinary research offers great opportunities for bringing holistic and innovative thinking, novel methods are needed to help reduce associated costs and ensure effectiveness and satisfaction with co-design and co-production.

Addressing risks and building resilience also require scientific knowledge that draws from and involves the intersection of many disciplines. All countries should develop the capacity to produce, access and effectively use scientific information in relation to relevant risks (Rovenskaya E. et al. 2021). International collaboration is an essential complement to local research capacities, particularly where local capacities are very limited. COVID-19 has shown us that even when countries have very limited scientific capacities, they can leverage global knowledge and policies to good effect. Linkages and networking are thus vital components of an effective response to crisis.

Open Science is crucial to increase the capacity of science to understand and tackle complex and urgent issues, while a widespread dissemination of existing and emerging scientific knowledge and breakthrough tools, approaches and solutions is key to fully revealing their transformational potential (S&T Major Group 2019). Member States, research institutions and science funders should work together to remove the barriers to published scientific knowledge and data and enable open access to published research. This is notably crucial for developing countries characterized by insufficient scientific and research capacity and limited access to high-quality, timely and reliable data, which can affect the ability of low-income countries to realize sustainable development, and scientific progress in general (Messerli P. et al. 2019).

Enhancing communication of scientific knowledge, public understanding and trust in science

Communication of science should become a critical component of the scientific endeavour, and to this end, scientists should be trained and incentivized. Communications to a broader audience could take different forms and be done through different means, for instance the utilization of visual and interactive tools should be widely encouraged. ISC's initiative, in partnership with the Australian Academy of Science, Global Science TV is a concrete example in this regard, aiming to share scientific expertise directly from experts themselves, while educating, entertaining and informing viewers on major issues of scientific relevance. In addition, the rapid increase of science distrust and misinformation during the pandemic, reveals the need for scientists to play a more active role in combating mis- and disinformation, in countering false claims and to defend the importance and integrity of science more rigorously. Individual scientists, but more particularly, science organizations must engage in urgent discussions on how to prevent the spread, and to combat mis- and disinformation, while respecting freedom of expression.

Better engagement of scientific communities with citizens in deliberative societal dialogues about the production and use of new knowledge could contribute to enhancing understanding of and trust in science. This could also be achieved through improving scientific literacy, which could become an integral component of science instruction in school, and should not only be focused on scientific facts, concepts and methods, but also on how science functions (Rovenskaya E. et al. 2021).

Improving science-policy interfaces at national, regional and global levels

The COVID-19 crisis brought to the fore the challenging but essential relationship between science, policy and society, highlighting some major shortcomings in how science has been used, instrumentalized, misused or ignored in the face of this novel threat. There is a need for improvement, including in advanced countries equipped with highly capable and institutionalized science advisory ecosystems (Colglazier 2020; Roehrl 2020).

Improvements should involve institutionalizing science-policy interfaces and building robust science-policy institutions at national levels, as policy advice always needs to be context-specific. In addition, international scientific cooperation amongst institutions operating at the science-policy interface is crucial. This can facilitate evidence- sharing and the emergence of a scientific consensus to be communicated to and used by decision- and policy makers. This is particularly critical for anticipating future global challenges and emerging threats, thereby allowing policy makers to take preemptive action (Rovenskaya E. et al. 2021).

Improving the effectiveness and quality of scientific advice while expanding its breadth requires the engagement in science advisory ecosystems of a diverse range of scientists coming from various scientific disciplines. In addition, increased transparency of science-advice mechanisms is critical to public trust and legitimacy which, in turn, will make policy implementation far more effective. This includes the need for scientists to be open about the limitations of their knowledge and level of scientific confidence in the policies they recommend. Another essential aspect in science advice is how evidence is communicated and formulated to policy makers, and in this regard, knowledge brokers as well as science communicators have an essential role to play and should be given sufficient attention.

Engineering Standards for a Changing Climate

William E. Kelly (Scientific and Technological Community Major Group; World Federation of Engineering Organizations; American Society of Civil Engineers)

Introduction

There are many different ways that science and engineering contribute to policy and governance and one way is by producing and maintaining good technical standards and advocating for their use. Technical standards are used broadly to protect public health, safety and the environment. Engineering standards are technical standards used in design of engineered systems.

In 2013, the United Nations established the United Nations Forum on Sustainability Standards (UNFSS) - a joint initiative of FAA, ITC, UNCTAD, UN Environment, and UNIDO.[2] In 2018, the United Nations Economic Commission for Europe (UNECE) co-organized with the International Organization for Standardization (ISO) a conference on the use of voluntary consensus standards in meeting the United Nations Sustainable Development Goals (SDGs) as a side event to the 41st meeting of ISO in Geneva.[2] The conference explored through case histories how standards can be applied to: SDG 6 Clean water and sanitation; SDG 7 Affordable and clean energy; SDG 11 Sustainable cities and communities; and SDG 13 Climate action.

There are many good introductory resources on standardization and many of them are available online. Standards are developed by national, regional and international standards developing organizations and by businesses and other organizations for their own use. Standards are also developed by consortia of businesses to address specific marketplace or industry needs, and by governments to support regulation. Standards are public goods and as such are an important contribution of professional societies and other organizations.

The International Electrotechnical Commission (IEC) defines an international standard as:

> *... a document that has been developed through the consensus of experts from many countries and is approved and published by a globally recognized body. It comprises rules, guidelines, processes, or characteristics that allow users to achieve the same outcome time and time again.*[3]

No distinction has been made so far between standards in general, consensus standards and technical standards. Consensus standards are developed following strict rules. Technical standards deal with technical systems or the technical aspect of systems and standards more generally with products and processes.

Voluntary consensus standards are just that voluntary. Voluntary standards become mandatory when they are incorporated into business contracts or government regulations. The ISO IEC document *Using and referencing ISO and IEC standards to support public policy* provides details for policy makers on how to reference ISO and IEC standards.[4]

Standards development

The American Society of Civil Engineers (ASCE) develops standards used globally in the engineering/construction sector. ASCE is developing a standard for design of sustainable and resilient infrastructure that is expected to be available in 2021.[5]

Accredited standards developing organizations (SDOs) like ASCE have strict rules that must be followed in developing standards. ASCE is an American National Standards Institute (ANSI) accredited standards developer and follows ANSI's essential requirements in developing its standards.[6]

Organizations developing international standards must comply with The World Trade Organizations (WTO) Committee on Technical Barriers to Trade (TBT) principles for standards development. The WTO principles are: transparency; openness; impartiality and consensus; effectiveness and relevance; coherence, and development dimension.

Standards in governance

Standards are incorporated into building codes by reference. Building codes are an important tool for improving both building sustainability and resilience as well as ensuring protection of public health and safety. The advantage to governments in using voluntary consensus standards is they take advantage of the engineering expertise in standards committees - expertise that may not be available in government.

One way that governments at all levels drive sustainable development is through their procurement practices. For the UN, sustainable procurement means taking societal and environmental factors into consideration along with financial. Common sustainability goals of procurement are to reduce material use and carbon emissions. This can be done are by using sustainable vendors and by requiring vendors to meet minimum standards for recycled content and for decarbonisation in goods and services. ISO has a guidance standard for sustainable procurement.[7]

According to the United Nations Office of Project Services (UNOPS) infrastructure affects 92% of the Sustainable Development Goals (SDGs). For UNOPS, there are two types of infrastructure networked and non-networked. Buildings fall into the non-networked category and systems for transportation, energy, water and sanitation, and communications into the networked category. In contrast to buildings, there are no codes for networked infrastructure design and construction. Instead there are design manuals developed at all levels from local to national that reference standards and specifications.

Impact of climate change

An important question today is do current standards in the engineering/construction sector - buildings and infrastructure - adequately address the changing climate? ASCE has officially recognized the potential for climate change to affect engineering practice for more than 30 years and recently updated its policy on the impact of climate change.[8] The issue as stated in the ASCE policy is that

> *Current engineering design standards, codes, regulations and associated laws that govern infrastructure are generally not structured to allow design adaptation to address climate change.*

In 2011, ASCE established a Committee on Adaptation to a Changing Climate.[9] In 2015, the committee published a report on adapting infrastructure and civil engineering practice to a changing climate.[10] In the same year, the World Federation of Engineering Organizations (WFEO) adopted a Model Code of Practice on Principles of Climate Change Adaptation for Engineers.[11] Principle 2 of the Model Code is to "Review Adequacy of Current Standards."

In the United States, the Government Accounting Office (GAO) noted the current belief that buildings and infrastructure are built to last whatever the climate. In reality GAO noted that current design standards and building codes are based on historical data and *do not recognize changing climate*. Further, GAO stated that continuing to build with current codes and standards could cost the federal government billions of dollars for repairs, flood insurance, and disaster relief and the GAO called for federal agencies to work together to provide better forward-looking climate information for updating codes and standards.[12]

The situation at the global level is no different. It is urgent that the codes and standards used to design buildings and infrastructure be updated now to reflect the changing climate and implemented and enforced.

Summary

Standards already play an important role in supporting achievement of the SDGs. Policymakers need to understand the important role that engineering standards play and could play in governance and in enabling the buildings and infrastructure needed to achieve the SDGs. Standardization is a tool that needs to be and can be used effectively at all governance levels from local to global. Education and capacity building on standardization and conformity assessment should be encouraged and supported utilizing the many resources already available.

The standards community and the engineering community in general need to be made more aware of the SDGs and how technology and standardization specifically can contribute to the SDGs. There needs to be a much broader effort to engage the science and engineering community on the SDGs. There also needs to be broader involvement of the science and engineering community including academic and industrial researchers in standardization activities

The global investment in the built environment and the additional investment needed to achieve the SDGs is enormous. The UN needs to take steps to protect the existing investment, ensure that we build back better and that all new buildings and infrastructure are resilient and sustainable. Updating building and infrastructure standards to address the changing climate is one important and necessary way.

Recommendations

The UN should endorse the WFEO Model Code of Practice on Principles of Climate Change Adaptation for Engineers and encourage WFEO to maintain and update the Code as appropriate.

The UN through the members states should encourage engineering societies and organizations to adopt and implement the WFEO Model Code of Practice on Principles of Climate Change Adaptation for Engineers

The UN should encourage and support member state efforts to update building and infrastructure standards for the changing climate.

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Emerging frontier tech must adhere to Rio Principles for SDGs to work

Tom Wakeford and Neth Dano (ETC Group)

Abstract

ETC Group has played a direct role in challenging two outdoor experiments involving rapidly emerging frontier technologies. Each experiment was promoted to advance the SDGs: one addressing health by reducing the number of malarial vectors in Africa and the other tackling climate change by spraying aerosols in the stratosphere to curb global warming. Both of these experiments put fundamental principles of sustainable development on the line, thus threatening the achievement of the SDGs.

Gene drive mosquitoes in Burkina Faso

A gene drive is a technique, currently still at the experimental stage, that is designed to spread particular genetic traits through a population. Gene drive organisms manipulate the normal sexual reproduction system, forcing a genetic trait into subsequent generations, such that it becomes dominant over a few generations[65]. Modelling suggests that gene drive experiments in the real world could be very risky, with altered genes potentially spreading to places where a species is not invasive but a well-established part of the ecosystem[66].

The international research consortium Target Malaria (TM) is working to create a gene drive mosquito that would reduce the number of *Anopheles gambiae* mosquitos, the females of which are vectors of malaria. The gene drive modifies the mosquito's fertility gene, causing the females to create only male offspring or not to have any offspring at all. These modified mosquitoes pass on their genes to a high percentage of offspring, spreading these auto-extinction genes throughout the population. In this way, potentially the entire species, could inherit that trait and thus become extinct.

TM is adopting a dual approach, involving the development of gene drive mosquitoes in laboratories at Imperial College, London, UK, in parallel with the release of genetically modified (GM) mosquitoes (not yet engineered to include gene drives) in two villages in Burkina Faso (Bana and Sourkoudingan), which began on 1 July 2019. By obtaining government approval for these GM releases, TM has eased the regulatory pathway for eventual later release of gene drive insects.

Parties to the Convention on Biological Diversity (CBD), which include the UK and Burkina Faso, are required to seek the approval of 'potentially affected indigenous peoples and local communities' prior to considering any release of gene drives, including experimental releases[67]. Investigations by ETC Group suggested that in communities in which the first GM mosquitoes were later released by TM, had not been properly consulted or informed about either element of the project[68]. Local people were therefore not able to make a decision that was based on hearing a balance of viewpoints. Local civil society groups have also expressed concern that there had been no published risk assessment undertaken of TM's experiments in Burkina Faso.

Geoengineering experiment in Sweden

Geoengineering is the intentional, large-scale technological manipulation of the Earth's systems, primarily to address the impacts of climate change. In 2010, the CBD adopted a de facto moratorium, stating that no geoengineering activities should be carried out until a "global, transparent and effective control and regulatory mechanism… in accordance with the precautionary approach" can be put in place.[69] The moratorium allows exceptions for small-scale experiments, but only if several conditions are met,

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including that they are conducted under "a controlled setting."

Harvard scientists have been undertaking the project Stratospheric Controlled Perturbation Experiment (SCoPEx) to investigate methodologies and hardware in conducting stratospheric aerosol injection (SAI), a solar radiation management (SRM) technology. If deployed, SAI is meant to reduce the amount of sunlight reaching the earth's surface by injecting sun-blocking particles into the upper levels of the earth's atmosphere. SCoPEx planned to launch their balloon in Kiruna, northern Sweden in June 2021 in partnership with the state-owned Swedish Space Corporation[70]. The date has now been postponed following a series of protests by Indigenous Peoples and civil society.

The conditions set by the CBD for geoengineering experiments in controlled settings are not met by SCoPEx. While the first stratospheric flight proposed for Kiruna intends to test the balloon and gondola equipment, the stated purpose of the flight was to prepare for the release of aerosols into the stratosphere later in the year in Kiruna. Since the goal of the initial flight is to enable the subsequent release of particles, this planned balloon flight must be viewed as integral to the project's intention of conducting open-air testing and particle release.

Solar geoengineering has the potential for massive negative impacts on the world's most vulnerable populations. Droughts in Africa and disruptions in monsoon patterns in Asia are among the major risks identified by computer modelling[71]. The sources of food and water for 2 billion people could be disrupted. SRM deployment would also lock in the world in this technology since aborting it could result to "termination shock" that involves rapid rise in global temperature[72].

Frontier technologies and the SDGs: using Rio Principles as lens

The Target Malaria and SCoPEx cases described above demonstrate the usefulness of the fundamental principles of sustainable development in interrogating the application of frontier technologies to address key developments challenges.

Precautionary Principle

Both cases, though still at research and development stage, underline the need to apply the Precautionary Principle. The principle emphasizes caution, pausing and review before leaping into new technologies that, if deployed may prove disastrous. Where there is doubt, the enactment of the precautionary principle does tend towards policies that prevent the release of potentially harmful technologies. The principle does not necessarily mean a ban on new technologies or stopping research, but urges that opportunities be created to address concerns using an appropriate range of perspectives.

Free and Prior Informed Consent

Any outdoor experiment of frontier technology applications need to undergo transparent, democratic and thorough consultations in communities, in particular indigenous and local communities, that will be potentially affected by the technology. Civil society in Burkina Faso have raised concerns on the absence of consultation and information in Target Malaria's release of GM mosquitoes and the parallel research on gene drive mosquitoes. The recent decision of the Swedish Space Corporation to postpone the SCoPEx open field trial in northern Sweden following objections from civil society, experts and indigenous communities.[73]

Access to information, participation in decision-making and access to justice in environmental matters.

In both experiments, there was barely any information provided to the public. Decision-making was limited to that provided by partner institutions in the country that hosted the field trials. Civil society in Burkina Faso have tried without success to access information on releases of GM mosquitoes from the government. The government-owned space centre in Sweden did not provide further details on the modalities of the experiment and the nature of its partnership with the proponents of SCoPEx. Public access to information is a prerequisite to meaningful community participation in decision-making on matters relevant to the

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environment. Transparency in decisions on field testing of frontier technologies is key to redress and liability in case of adverse consequences to the environment and people.

Intergenerational equity

Gene drive organisms would change the dynamics among organisms in an ecosystem, would disrupt ecological balance and have unknown consequences on the environment and people. Stratospheric aerosol injection would lock the world into a technology for generations since halting its deployment would result to "termination shock" that could dangerously exacerbate global warming.[74] Deployment, including real-world experiments, of frontier technologies that are largely untested, speculative and potentially dangerous for the planet that will be inherited by the next generations, thus violates justice principles.

Avoiding technology lock-in

There is common feature in both experiments described here, which is that they are a Trojan Horse - a 'first-step' experiment designed to clear the way for more significant interventions in the near future. In Sweden, the objective of the initial SCoPEx flight was presented as being merely to test equipment but was seen by many as a deliberate attempt to normalise the move to experimentation with aerosol release in the stratosphere. In Burkina Faso, Target Malaria are explicit that they are releasing GM mosquitos without gene drives as a means to test and prime the regulatory system for later gene drive releases. In each case, those recommending precaution are not simply highlighting the risks posed by a specific experiment, but questioning (and rejecting) the wider policy direction behind the experiment. Researchers on new technologies have identified the related syndrome of 'lock-in', whereby deepening institutional and economic commitments to big science projects create a path-dependence, leading to decision-makers becoming locked-in to deployment and commercialization of those projects when they are not necessarily the best option. Calls to move away from precaution towards 'case by case' policy making risks increasing such path-dependence.

Policy recommendations

To attain the aspiration of the 2030 Agenda for Sustainable Development to "leave no one behind", the Rio Principles must remain as the fundamental metrics for consideration of new and emerging technologies as tools to attain the SDGs. Broad societal deliberation on frontier technologies and their potential environmental, health, economic and social impacts must be a prerequisite for their development and deployment. Participatory mechanisms for evaluation of new and emerging technologies need to be established at the global, regional and local levels. The UN should help provide countries and institutions with technology assessment and horizon-scanning capacities, as envisioned in the "Future We Want" outcome document of Rio+20[75],[76].

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Policy approaches to direct frontier technologies towards inclusive and sustainable development in Asia and the Pacific

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Note: This policy brief is extracted and updated from ESCAP (2018). The views expressed are those of the authors and do not necessarily reflect those of the United Nations or its senior management.

Abstract

Frontier technologies such as artificial intelligence (AI) have played an active role in fighting against COVID-19 pandemic in Asia and the Pacific. Going forward, it will be critical that frontier technological breakthroughs such as AI, robotics, 3D printing, and the Internet of Things, amongst others are aligned with the 2030 Agenda for Sustainable Development. This policy brief stresses that while there are question marks over the scale and pace of the frontier technological transition, it would be prudent for governments to be prepared, and to put effective policies in place. To this end, this policy brief outlines a few prerequisites for the development and application of frontier technologies.

Background

During the COVID-19 pandemic, frontier technologies such as AI showed their usefulness. For example, by adopting AI, Republic of Korea was able to develop much needed diagnostic kits within a month in the. For another example, hospitals in Thailand adopted AI solutions and 5G tech to fight COVID-19. The ubiquitous applications of frontier technologies in Asia and the Pacific have been discussed in ESCAP (2020).

Moving forward, and in the context of 2030 Agenda for Sustainable Development, frontier technological breakthroughs such as AI, robotics, 3D printing, and the Internet of Things amongst others carry the transformative potential. On the other hand, adoption of these technologies is tempered by increasing concerns about the potential negative impacts such as job losses to automation and increased inequalities.

This policy brief examines key opportunities and challenges of frontier technologies in relation to sustainable development. It proposes some key policy priorities that could form the basis of a next generation technology policy framework for the Fourth Industrial Revolution future and ensure that frontier technologies more deliberately align to the ambitions of the Sustainable Development Goals (SDGs).

Challenges for harnessing frontier technologies for sustainable development

To effectively develop and implement frontier technologies for sustainable development, challenges vary depending on the context in a country or industry. This section highlights two common areas where impacts of frontier technologies may not necessarily produce sustainable development results, namely, 1) the impacts of frontier technologies on jobs, and 2) a new frontier technology divide.

The impacts of frontier technologies on jobs

Debates on the impact of frontier technologies on jobs are abundant in existing literature. Despite the numerous forecasts on how automation or robots will replace human labour, many existing studies mainly focus on the technical feasibility of job displacement while neglecting the factor that what is technically feasible is not always economically viable (see Figure 1).

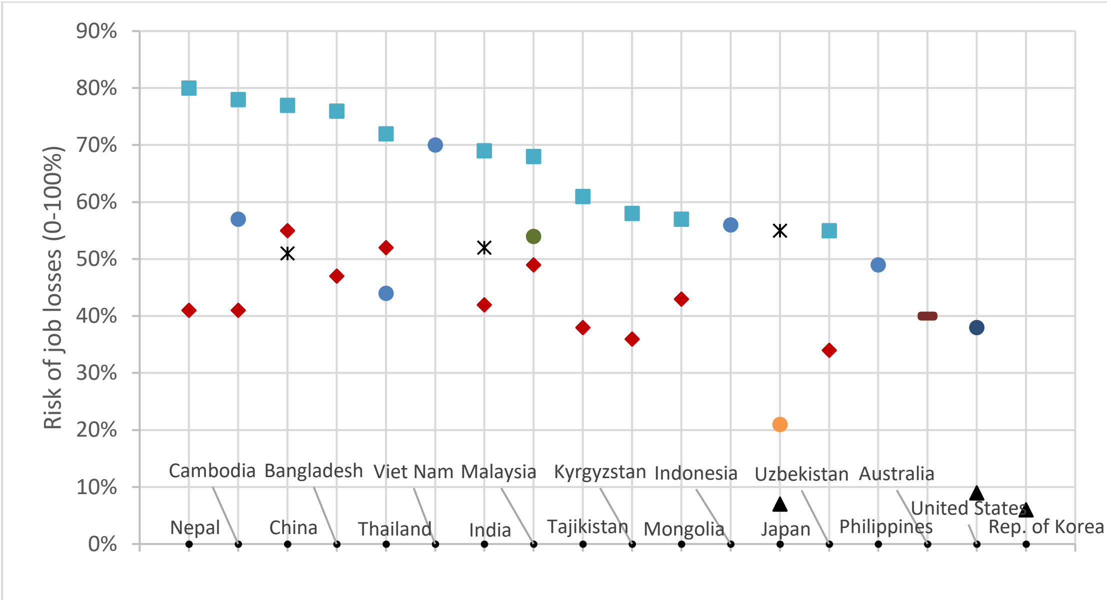
Ultimately, decisions on the adoption of automation technologies often hinge on cost-benefits analysis. Nevertheless, the nature of technological displacement of labour is about how fast rather than whether it will happen. Market mechanisms will dictate that start-ups, SMEs, corporations and industries, choose the most cost-effective method of production.

The digital and new frontier technology divides

As ICT infrastructure is the backbone of many frontier technologies, there is a risk of a new frontier technology divide on the back of already existing digital divide. For example, available data show that 17 out of 31 ESCAP member countries continue to have less than 10 broadband subscriptions per 100 inhabitants in 2019(as shown in figure 2).

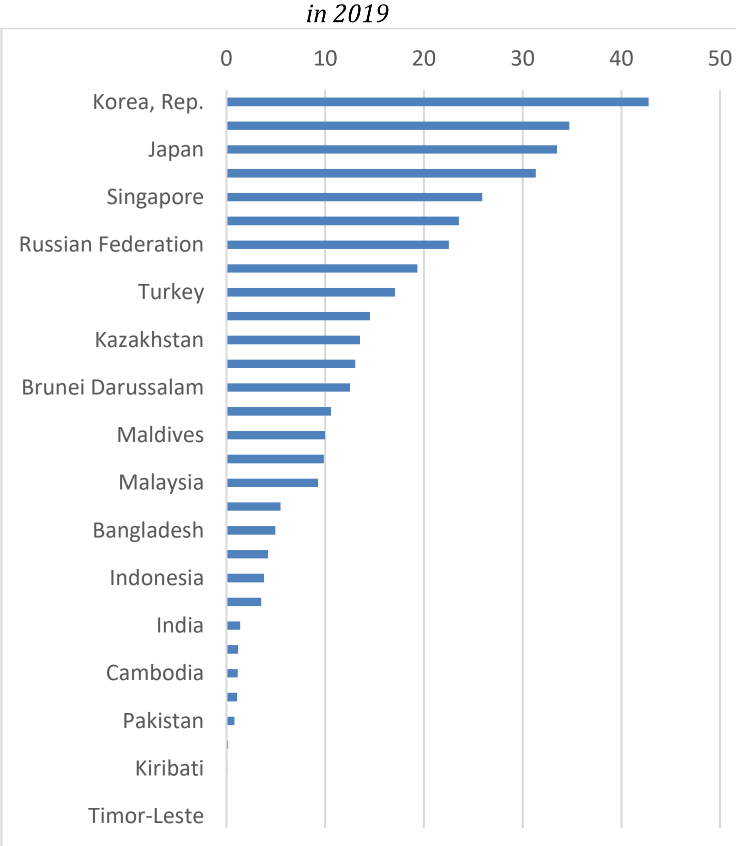
Another perspective to assess the frontier technology divide is gross domestic expenditures in research and development (R&D) as per cent of the GDP (as shown in figure 3). Of the 23 countries for which data are available, only three countries in the region –China, Japan and Republic of Korea – spend 2 per cent or more of GDP on R&D. On the other end of the spectrum, almost half of the countries spend 0.25 per cent or less.

Figure 1. Range of estimates of the share of jobs at risk of being lost to automation



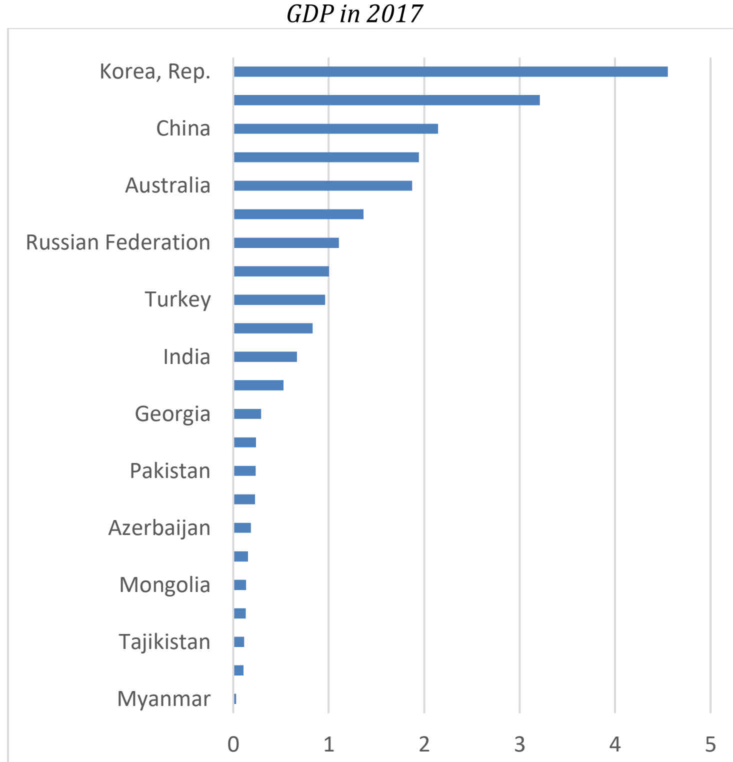
Source: Compiled by the ESCAP study team according to the existing studies, as shown in the figure. *Note:* The sample in the figure include countries in ESCAP region. United States is included for benchmarking. Further information is available from ESCAP (2018).

Figure 2. Fixed-broadband subscriptions per 100 inhabitants in 2019



Source: ESCAP based on ITU World Telecommunication/ICT Indicators Database (https://data.worldbank.org/indicator/IT.NET.BBND.P2, accessed in April 2021)

Figure 3. Gross domestic expenditure on R&D as a share of GDP in 2017



Source: ESCAP, based on data from UNESCO Institute for Statistics Data Center. https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS (accessed April 2021).

Policy priorities

As an initial step towards understanding the policy response to the opportunities and challenges that frontier technologies present more broadly, this section discusses six key policy areas that could form the backbone of a next generation technology policy which focusses on creating an enabling environment for frontier technologies, and is aligned to sustainable development objectives.

Inclusive ICT infrastructure

As discussed earlier, a prerequisite for the development and application of frontier technologies is developed ICT infrastructure. As shown in figure 2, ICT usage is unequally distributed among countries. Even if middle-income and to some extent low-income countries are not at the forefront of developing frontier technologies, equalizing opportunities embedded in the possibility of buying such technology or adapting parts of it to local circumstances could be lost if digital infrastructure deficits persist. In this regard, a continued focus on bridging the digital divide - particularly "last mile" connectivity - should be a policy priority so as not to fuel a new frontier technology divide.

Developing a workforce fit for a Fourth Industrial Revolution future

While the scale and pace of frontier technological adoption and diffusion and their impacts on job losses are largely unknown, it would be prudent for governments to develop a workforce fit for a Fourth Industrial Revolution future. Some directions to consider include: a greater emphasis on entrepreneurship training to develop job creators as well as job seekers, adult education, life-long learning, and reskilling to deal with current and future technological transitions. Education must also instil new expectations about work and the marketplace for jobs. In addition, governments could strengthen social protection systems to protect the workers that are vulnerable to losing their jobs. Such forward-thinking policies could support a strategy to facilitate redeployment, not unemployment.

Developing innovative regulatory frameworks

To avoid hindering the development of frontier technologies' application for sustainable development, regulatory processes need to become responsive and adaptive. However, enabling regulation for innovation is difficult to formulate and as such, innovations in regulation processes are urgently required.

Effective regulation should allow innovation to flourish while still safeguarding society and the environment. Balancing these demands will be an important government agenda as frontier technologies evolve, and one that will require sharing effective practices and innovative approaches between governments.

Incentivizing responsible frontier technology development in the private sector

Shared value

As the predominant investor in frontier technologies, the private and business sectors will shape how they impact the economy, society and the environment. However, to create positive impact on these three dimensions of sustainable development, corporations need to move beyond the concept of corporate social responsibility and redefine their objective, and associated measures of success, as creating "shared value".[77]

Governments can play a critical facilitating role by creating an environment to ensure the development, adaptation and diffusion of frontier technologies by the private sector is appropriate to their own country context. Typical measures can be subsidies or tax incentives for the development of products by the private sector which bring substantial societal or environmental benefits, especially these related to the SDGs.

Public-private partnerships

Public-private partnership can take many forms. For instance, a government can promote and drive joint research with the private sector and academia in the areas of strategic national interest or direct effects on public good. Governments may also provide support to the private sector for implementation of pilot projects. For instance, a private company will need government support to test a driverless bus in a city.

Engaging the technology giants

Leading technology companies could be important partners for addressing the SDGs. Efforts by leading global technology companies to make frontier technologies publicly available and transparent would enable developing countries to learn about the latest

[77] Shared value is not corporate social responsibility. It measures value across the three dimensions of sustainable development at the core of business strategy. To further promote shared value, policymakers need to create the right incentives, so these values move from corporate social responsibility departments to the boardrooms.

developments and identify solutions to social and environmental issues.

On the other hand, technology companies may dominate their respective sectors. This restrains effective market competition and lead to winner-take-all market outcomes. While the important role of the private sector in sustainable development has been well noted, government's need to put effective policies in place to manage any potential conflicts between maximizing corporate objectives of maximizing shareholder wealth, and potentially negative social and environmental impacts.

Catalyzing the role of government in frontier technologies' evolution

Public sector innovation skills

It will be critical for government and public sector workers to develop innovation skills if countries are to meet the diverse range of goals set out in the SDGs. Governments will need to support an agile, forward-thinking and technologically skilled civil service to respond to a rapidly changing world and the opportunities frontier technologies present.

The government as a market maker and shaper

While the private sector has been the prime investor in frontier technologies, increasingly, governments in the Asia-Pacific region are establishing dedicated agencies to help realize the transformative potential of frontier technologies. For example, the creation of SGInnovate complements the Singaporean Government's strategy to boost the country's frontier technology capabilities, through its government-wide partnership and national programme on Artificial Intelligence Singapore.[78]

Creating a platform for multi-stakeholder and regional cooperation

Cross-government cooperation; inter-governmental knowledge-sharing and consensus-building; and honest, open and regular discussion with civil society and the private sector, specifically technology developers will be critical to ensure that frontier technologies have a positive impact on sustainable development.

As a first step, developing a set of overarching principles governing the development of frontier technologies should be a first order priority. Globally, leadership on such an endeavour has been sub-optimal. Given Asia and the Pacific's prominent position in several frontier technologies, the region is well placed to lead on governance globally, to build trust and ensure effective deployments aligned to the SDGs.

Conclusion

This policy brief argues while there are questions over the scale and pace of the frontier technological transition, it would be prudent for governments to prepare and put effective policies in place. It emphasizes policy areas that could form the basis of a next generation technology policy fit for the Fourth Industrial Revolution future. Creating an enabling environment for frontier technologies to positively impact economy, society and environment, and to reduce current and potential inequalities should also be a fundamental principle of future technology policy if it is to effectively support the SDGs.

Many countries in the region are developing specific frontier technology policies and Fourth Industrial Revolution strategies however, they are in their infancy. To support countries to prepare, the evaluation of the impact of these experimental strategies should be a policy priority to establish what works and equally importantly, what does not. Through these activities, best practice next generation technology frameworks can be developed.

Finally, cross-government cooperation; inter-governmental knowledge sharing and consensus building; and honest, open and regular discussion with the civil society and private sector, specifically technology developers, will be critical to ensure that frontier technologies have a positive impact on sustainable development. The United Nations system is well positioned to play a critical role in this regard.

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[78] More information is available from https://www.nrf.gov.sg/programmes/artificial-intelligence-r-d-programme.

Principles for the Inclusive Data Governance

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Abstract

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. The article suggests three principles for inclusive data governance, i.e., fair data, transparent algorithm, and trustworthy architecture to address the growth with balancing the values.

Introduction

Two streams are approaching after the wave of the fourth industrial revolution. On the one hand, machines get famous in intelligence-based areas. Scientists, entrepreneurs, and government officers have focused on developing the AI technologies and their use cases since the Summer Research Project on Artificial intelligence in 1956 (Nilsson 2009). In the last decade, artificial intelligence leaped atop neural network's deep learning and brought the match between the machine representative and the human representative in Go, which has too many possible combinations ($\sim 250^{150}$) to search for the optimum path (Silver et al. 2017). Now, ordinary people as well as scientists and engineers harness the machines learning from big data in various areas, including translation, self-driving, and drug development. The wave of artificial intelligence finally stimulates human beings to compete and cooperate with machines in a new way (Brynjolfsson and McAfee 2014).

On the other hand, data become commodities as machines demand them. Digital platform providers take advantage of leading artificial intelligence as they possess the data accessible for machines to learn; therefore, Google, Salesforce, Amazon, and Facebook belong to the ten best artificial intelligence companies list (Divine 2021). Data also pour out of physical platforms and public databases such as factories, supply chains, credit cards, and healthcare records through the 5G network and the internet-of-things, and business opportunities emerge at processing and analyzing them (Nations 2019). However, those data mainly accrue on the field far from artificial intelligence and quite dirty for machines to directly study, a situation different from digital platforms. Therefore, governments suggest building a business ecosystem to share, recombine, reuse, and commercialize data in their programs, such as South Korea's Digital New Deal (Stangarone 2020).

Balancing the Values Around Data

Those trends remind us of time-honored issues on data governance, i.e., balancing economic benefit and human dignity. Data are the basis of fundamental rights from human dignity that have been institutionalized for centuries, while business opportunities accrue at accessing the data in all dimensions, including financial transactions and health in the new economy (Cheung 2020). For social benefits, too, we shouldn't forget fundamental rights before national security (US Government Accountability Office 2020) and innovation for economic growth (Furman and Stern 2011). Recent regulatory changes (e.g., the EU's General Data Protection Regulation) reflected the advanced artificial intelligence and opened the data economy. They shift the balance from captivating data in organizations with informed consent on specific purposes to sharing across organizations after anonymization or pseudonymization with a comprehensive agreement.

However, the recent trends of artificial intelligence and data economy make value re-balance complex. The foremost issue is the proportionality between reidentification and business opportunities. Business opportunities rely on machine's capacity and the quality of learning data. However, machines can also reidentify individuals with clues from personal data (Gymrek et al. 2013). Therefore, it is hard to encourage economic benefit at the moment, separately keeping human dignity. The upcoming governance dispersing across stakeholders intensifies that complexity. Data transfer to final goods through integration, cleansing, and analysis by third parties (European Commission 2017). Therefore, the market implies the responsibility ambiguity for data misuse increases as they transfer from the data owner to final data sets. In summary, no organization might take the consequences even if machines isolate people from their data.

Principles for Inclusive Data Governance

The complexity might undermine the value balance, which had already shifted for preparing the future because hiding identity in data and positioning the accountability to organizations are hard to work in the new economy. This article suggests three principles for data governance to prevent the expected loss of value balance: fair data, transparent algorithm, and trustworthy architecture.

First, artificial intelligence in the data economy needs **fair data**. Recent artificial intelligence based on neural networks determines their parameters according to their learning materials. Machines' decision will be biased if some part of databases limits their *access*: e.g., the artificial intelligence medical doctor provides a poor with the wrong diagnose or a wrong decision in the worst case in the case of the limited access to the poorer's healthcare database (Dana and Bernaert 2020). Furthermore, machines will also decide if human beings feed machines the *prejudice*, and their outputs will discriminate human beings, e.g., estimating a higher crime rate for blacks than white as their learning materials depict it (Garczarek and Steuer 2019). It is weighty that machines' discrimination might *span* family members and generations, as the data show the details of an individual what they share with family, such as inherited diseases (Yim et al. 2020).

Second, **transparent algorithms** should manage the data. Burrell (2016) said that algorithms get opaque when artificial intelligence vendors hide their source codes as a trade secret, people are illiterate in artificial intelligence technologies, and machines' interfaces are different from human beings. Technologies generally have those features, but their impact is profound on artificial intelligence because they are in charge of the decision. Let us recall the crime estimation. A lawyer will ask the judge of their reasons for sentencing if the judge is a human being. But the court will not discuss their decision if a machine judge returns only the sentence from the input data through their sophisticated neural networks with the parameters adjusted by judicial precedents. Therefore, the US Defense Advanced Research Projects Agency funds the explainable artificial intelligence (XAI) to follow up their decision process (Lukianoff 2019).

Third, a **trustworthy architecture** should overarch the data transfer. William et al. (2019) highlighted trust as the enabler of data flow in the data economy. Many data economy projects, including Korea's Digital New Deal (Stangarone 2020), consider blockchain and distributed ledger technologies as a trust infrastructure, as data on-chain are immutable and anonymized. I agree that blockchain is currently the best solution to build trust. Still, the architecture leaves issues. Off-chain data passes through a particular node called *Oracle* before uploading on-chain. Oracle is a weak point of blockchain because it is the only centralized node in a decentralized architecture (Antonopoulos and Wood 2018). Furthermore, the *capitalist reward scheme* centralizes the decision power so that the wealth inequality might demolish the democracy of machines (Park, Kim, and Kim 2020). Therefore, trustworthy architecture demands governance for trust on those weak sides.

Conclusion

The recent trends pave the pathway to a data-driven society where the data economy feeds data to machines returning processed data to the economy. The upcoming world promises business opportunities that enhance individuals' utility and social benefit when third parties harness the data originating from various sources. But it also involves the risks of losing the value balancing if the changing ethical and regulatory frameworks remain at hiding personal information from raw data and positioning accountability to organizations. This article proposes global leaders discuss inclusive data governance based on fair data, transparent algorithms, and trustworthy architecture.

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C. Digitalisation, artificial intelligence and robotics

Potential Threats of Human Digital Twins for Digital Sovereignty and the Sustainable Development Goals

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Abstract

Human digital twins (DT) provide new ways of processing the activities of its user and are able to exert significant influence on the behaviour of individuals. As the technology promises manifold business opportunities, widespread incorporation is highly likely but may lead to a variety of social, environmental and technological challenges. A new regulatory context is needed to face possible downsides and foster an ethical and lean digitisation approach. This brief provides a concrete definition, a description of the implications and the respective policy recommendations.

Digital Twins - a Definition

Digital Twins are a virtual representation of physical objects with a bilateral exchange of information. A *human digital twin* is, therefore, the aggregation of human related data that is supposed to represent its real counterpart in the virtual world. A (human) digital twin continuously controls and monitors its physical twins' status, with the aim of optimizing its performance by triggering self-optimisation and self-healing mechanisms (Barricelli et al., 2020).

Problem Statement

Digital Twins (DT) are a new technological approach combining the capabilities of distributed sensor technologies, artificial intelligence, big data analytics, cloud computing and shared databases to create a digital virtual representation of a physical object. They have first been used in industrial applications such as aviation or production systems (Uhlenkamp et al., 2019), but are increasingly applied to monitor, represent, and influence human behaviour. A human DT is formed by large amounts of data produced by physical and virtual objects we interact with (e.g., fitness trackers, social media tools, smart watches, search engines, etc.) to support behavioural analysis and prediction. As the goal of digital twins is the optimisation of certain behavioural traits (such as health-status, user-activity in a system, response to ads, etc.), its feedback to the physical object is designed to achieve this goal.

Possible instances of this technology are widespread and include but are not limited to professional (Nikolakis et al., 2018), medical (Martinez-Velazques et al., 2019) and leisure activities (Barricelli et al., 2020). The usage of personal data has been a sensitive topic of legislation and was also discussed during the pandemic of COVID-19, when population monitoring and *nudging* of behaviour (Leonard et al., 2008) was suggested as political means to mitigate the crisis.

However, the advent of digital twins marks an evolutionary step in surveillance and profiling intensity. Reports indicate that by 2023 individual activities will be tracked digitally by an *Internet of Behaviour* to influence benefit and service eligibility for 40% of people worldwide, which might rise to 50% in 2025 (Plummer et al., 2020).

As this trend continues, an *extensive digital replica of one's personality* (also called *human digital twin*) poses significant threats to the digital sovereignty of individuals, democracy and nations as whole; but also for achieving the sustainable development goals (SDGs) in a variety of fields, such as:

Automated processing of profile data—often of unclear quality assurance: Existing societal biases can be reinforced by unfit designs of human digital twins, algorithmic feedback loops and simple statistical correlations. Without transparent and ethical use of DTs, predominant inequalities (e.g., SDG 5 – Gender equality, SDG 10 – Reduce inequalities) can be enhanced and damage well-being and amplify societal fractures (World Economic Forum, 2021). This risk is especially salient when machine learning ("artificial intelligence") is used for decision making, as these techniques are often non-transparent by design (Birhane, 2021).

Unregulated access to personal data and the digital twin itself: Personal data and the DT itself might be accessed by or sold to third parties which could restrict access of vulnerable groups to economic and social resources (e.g., application for insurances, loans, welfare, schools, jobs). Without reasonable restrictions and democratic oversight, this increased transparency poses a threat for achieving inclusive education (SDG 4), inclusive economic growth (SDG 8), equal opportunities and the reduction of inequalities of outcomes (SDG 10). In this regard, human digital twins also pose serious risks for the sustainable development of identification systems (SDG 16) (World Bank Group, 2021), as the (unregulated) use of such could be detrimental to an inclusive and privacy endorsing design.

Foreign data ownership: The accumulation and computing of personal data is often outsourced to servers or cloud services in foreign jurisdictions. The increased attack surface within such hyper-connected cloud environments and the creation of single points of failure foster significant privacy and security risks (Allianz Global Corporate & Specialty, 2021). As a consequence, data sovereignty of individuals, companies and nations as well as the resilience of national infrastructures (SDG 9 – develop quality, reliable, sustainable and resilient infrastructures) will be harmed as the dependence on services hosted by foreign providers increases.

Shadow human digital twins: Human digital twins can be created of people who did not consent to provide personal data. However, the accumulation and application of data from other people can be sufficient to indirectly infer a DT for individuals who are not even registered in the specific service (e.g., friends "tag" photos with names or location, email communication or calendar). Consequently, data leaks could expose people and organisations without their knowledge and undermine their activities (SDG 16 – peace, justice and strong institutions).

External influence of one's behaviour ("targeting"): The received feedback from human digital twins is designed to change the behaviour of the targeted object. Non-transparent and unethical designs of such intended behavioural changes bare manifold societal, psychological, and ethical risks (see for instance the attempts to change the outcome of elections).

Self-reinforcement of existing opinions, worldviews, and prejudices: Individual human digital twins can be designed to maximise interaction (e.g., "engagement" in social media) or to influence one's behaviour to increase prediction accuracy with less user variance. This can lead to reduced variety and complexity of presented information, increased information segmentation, and self-reinforcement of certain behavioural patterns (Kaakinen et al., 2020; Bhargava et al., 2015). As this imbalance of information will be increased, it poses a severe threat to democratic processes, the situational capacity to tackle existing threats (e.g., mitigation of climate change) and further aggravates the ongoing erosion of social cohesion and global cooperation (World Economic Forum, 2021). This type of reinforcement is in stark contrast to SDG 4 (knowledge to promote sustainable development), SDG 12 (ensure that people have the relevant information for sustainable development), SDG 13 (improve education and awareness on climate change) and SDG 16 (ensure public access to information).

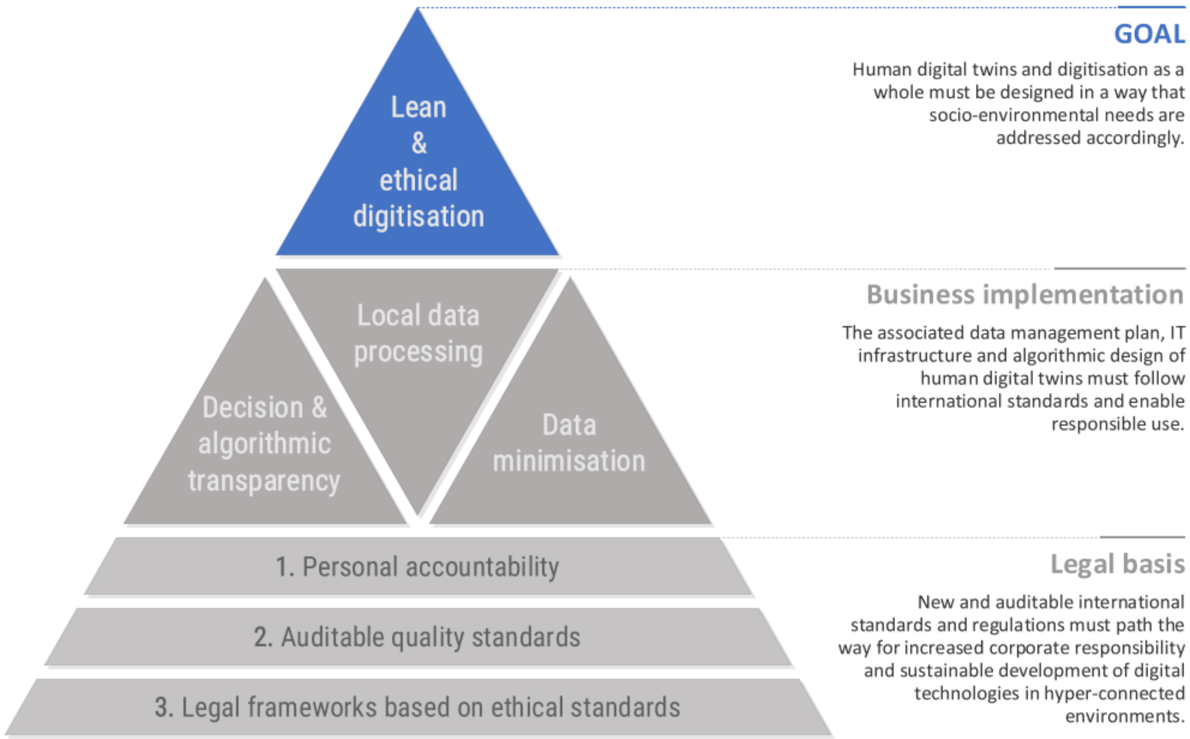
Policy Recommendations

We call for a *lean and ethical digitisation approach.* This is based on a principle that has already been described within Art. 5 GDPR as "data minimisation", which can be perceived as "an attitude to how we capture and store data, stating that we should only handle data that we really need." This principle forces us to figure out the minimum amount of data required to achieve the defined goal of a DT but should be extended in a way that requires incorporation of ethical standards and open communication of what we really intend to do with the digitisation approach.

Digital twins are designed to "make decisions" for their human counterpart. Next to *data transparency, decision transparency* is required to keep these processes fair and democratic. It should be critically reviewed how "black box" algorithms (like machine learning, artificial intelligence algorithms) that operate on behalf of people or make autonomous decisions that cannot be explained are applicable to transparency requirements. Such algorithmic transparency is necessary for reviews regarding mutually accepted ethical standards and further legal regulation.

A subsequent aspect is the *processing location of data.* Currently we see two paradigms at play, whereas the first and increasingly dominating principle—for digital twins but also in a more general way—is cloud/centralised computing. This has the distinct disadvantage that is inherent with centralised architectures: security and reliability issues affect large numbers of customers at the same time, and whoever has access to the processed data could exploit it (e.g., correlating data between customers, selling data). The second approach is to keep processing and computation (e.g., facial recognition, email indexing) on the customer device and only exchange data to central processing or for sharing with other users that were explicitly selected by the user.

Figure 1: Lean & ethical digitisation approach



If implemented carefully, this leads to more robust application performance and tends to support data minimisation, digital sovereignty and avoid single points of failure. Switching from centralized data centres to edge devices may reduce energy consumption due to less data transmission and decreased cooling of data centres. Furthermore, the closeness of edge-devices to distributed renewable energy sources may enable efficient energy demand management in smart grid systems (Digital Future Society, 2020).

Currently, *business models* dominate certain sectors of IT services (such as social networks, news sites, communication tools) that have their foundation in surveillance or tracking of customers, collecting and trading personal data, and manipulating their users on behalf of their business customers (Zuboff, 2019). Human digital twins extend the capacities of such business models extensively and their incorporation in such should therefore especially be reviewed critically. *Legal frameworks* that aim for *data minimisation, algorithmic transparency* and *local over central processing (Figure 1)* would mark a first step to limit associated societal threats. Regulators should be wary of businesses influencing drafting processes through lobbying efforts.

Existing frameworks (e.g., Sarbanes-Oxley-Act, GDPR) sanction failure in compliance, but prosecution can be cumbersome. As the sense of urgency in organisations to enforce and follow regulations may be lacking, novel legal frameworks should foster an increase in *organisational responsibility and personal accountability* of individuals in leadership to implement adequate measures towards accountability, resilience and the protection of data subjects. Furthermore, circumvention of these frameworks must not be possible by "freely given consent" (e.g., GDPR Art. 7 & Recital 43), as this requirement will often remain heavily imbalanced towards the interests of large companies as data collectors and controllers.

Finally, quality and scaling issues in increasingly complex IT infrastructure pose high risks for the resilience, security and privacy of our digital ecosystems. Therefore, auditable *international quality standards* for human digital twins and their respective software, architectural, process and security designs must be defined.

Whereas the threats of human digital twins are diverse, responsible incorporation could also support ongoing endeavours (e.g., profiled data for energy demand management within smart grid designs) in achieving the SDGs.

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Digital Currencies: a definitive push to achieve the Sustainable Development Goals in Developing Countries?

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Note: The views expressed are those of the authors and do not necessarily reflect those of the United Nations or its senior management.

Abstract

Central bank digital currencies (CBDCs) appear to be the next step in the evolution of digital currencies after the Bitcoin and stable coins. Indeed, more and more central banks are now contemplating the development of CBDCs while a very few are starting to implement their own CBDC. Banking the unbanked and improving financial inclusion are among their main promises. However, this paper makes the case that, without including the voice of the most vulnerable, CBDC may further deepen the current digital divide. In addition, the creation of a national CBDC may have spillover effects in developing countries. More research is needed to better assess the potential impacts of CBDCs for developing countries, affecting the vulnerable populations the most. To ensure we leave no one behind, we must raise awareness among developing countries and ensure their interests are reflected in international forums discussing the issuance and regulation of digital currencies. Finally, we suggest using existing intergovernmental processes with universal membership to monitor and provide guidance on these discussions, such as the ECOSOC Commission on Science and Technology for Development, which is the UN's home for discussion on science and technology.

The financial realm is buzzing around Bitcoin and digital currencies in general. Bitcoin launched in 2009, but the first wave of market enthusiasm began in November 2013 when its value peaked at US$1,213. Since then, an increasing number of companies have accepted bitcoin as a means of payment, and many countries have either formally or informally permitted buying and selling bitcoin. That said, the high volatility of bitcoin currently limits its potential as a mainstream currency for the purchase and sales of goods. In one month, bitcoin dropped from $41,973 on January 8, 2021, to $33,078 on January 24, bouncing back up to $50,000 on February 16, 2021.

As a response to bitcoin's volatility problem, several private entities have issued stablecoins. Stablecoins achieve value (price) stability in one of two ways: (1) pegging to another currency or commodity (or basket of currencies/commodities) through collateralization, or (2) controlling stablecoin supply through algorithmic buying and selling mechanisms. For collateralized stablecoins, volatility will fluctuate along with the funds or assets whose values fluctuate – arguably, this variance is minimal.

Central banks have noted digital currencies for their unique benefits and risks and are exploring a third option: a central bank digital currency (CBDC). In the last quarter of 2020, the Bank for International Settlements reported that 86% of the central banks surveyed are studying CBDCs.[1] This work is increasingly shifting from research to practical experimentation – bringing CBDCs closer to everyday reality. In 2020, the Bahamian Sand Dollar became the world's first general-purpose CBDC, with China, Sweden, and the Eastern Caribbean Central Bank, among others, not far behind. Companies using proprietary, often open-source based technologies have provided the technological infrastructure to support CBDCs, and are developing quickly in number and sophistication. CBDCs are featuring strongly in academic, financial, and intergovernmental conversations. *CBDCs are here, and development is accelerating.*

What are Central bank digital currencies (CBDCs)?

CBDCs, in their simplest form, are a digital representation of fiat currency – currencies backed, issued and controlled by a central bank. Like physical bank notes, CBDCs are a direct claim against a central banks rather than a commercial bank or other intermediary's liability. CBDCs are legal tender and part of the base money supply, whether they ultimately replace or complement current cash systems. They are distinct from payment systems but will likely compete with cryptocurrencies like bitcoin and privately issued currencies like Facebook's forthcoming Diem. With

[1] Boar, C. and A. Wehrli. (January 2021). *Ready, steady, go? – Results of the third BIS survey on central bank digital currency.* Monetary and Economic Department. BIS Papers. No. 114. JEL classification E42, E58, O33. ISSN 1682-7651. ISBN 978-92-454-1.

central banks as the trusted controlling entity, CBDC aims to be as value stable as cash.

All CBDCs require a database to record exchange and ownership of the currency. This database can use blockchain or existing ledger technology. Currently, private blockchain – or permissioned blockchain – are being considered against public blockchains (like Bitcoin) which have been ruled out for their inability to meet criteria such as appropriate security, speed, scale, privacy, accessibility (including offline), fraud resistance, interoperability and legality. .

CBDC – a game-changer for financial inclusion?

CBDCs hold great promise for improving financial inclusion. CBDCs can reduce the risks associated with storing, handling, and transporting physical cash. CBDCs can provide easier access to financial services and instruments, such as savings (and perhaps even pay interest), loans, equity and insurance, to unbanked populations compared to current fiat systems. CBDCs can facilitate many financial transactions that are difficult or costly with the existing banking system, such as remittances, trade and e-commerce financing (local and international), investments, among others. CBDCs can improve the speed and target ability of cash transfer schemes, getting timely humanitarian aid, social payments, or even pandemic relief into the hands of those who need it. However, *these promises require designing the CBDCs with leaving no one behind as a forethought.*

Making CBDC accessible and affordable is a significant challenge. Access to reliable and affordable electricity, Internet and necessary hardware, such as smartphones or computers, is challenging in more impoverished, rural and remote areas.[2] At the end of 2019, about half of the world's population did not have access to the Internet, among which women are a majority.[3] Should CBDC design not appropriately account for access and affordability, the digital and gender divide is at risk of widening.

Digital and financial literacy at the household and individual level must be sufficient to protect against misuse or digital financial abuse. Some countries are already experiencing an emergence in digital currencies financial scams and fraudulent activity. As with other emerging technologies, the implementation of CBDCs without appropriate mitigation measures may further increase inequalities between those who can safely interact with CBDC and those who can't.[4]

Successfully transitioning to CBDC requires adequate institutional capacity. Leadership will need to have a certain comfort level with the architecture and usability of CBDC as new technology. Domestic legal tender laws will need to be well aligned with digital currencies to avoid issues related to the legitimization of payments, security and custody of CBDC. A national digital identity system is also likely to be necessary to facilitate e-wallet – the individual accounts which give access to digital currencies - and CBDC account ownership verification.

Digital currencies require a fresh look at how we reduce inequality and leave no one behind

Identifying and understanding the impacts of CBDC in mainstream use is primarily limited to assumptions and predictions based on a handful of pilot projects. However, it is evident that *the impacts and opportunities of CBDC are not trivial.*

At the country level, CBDCs may reduce costs of maintaining fiat currency, including fraud detection. New foreign direct and indirect channels may open up, depending on CBDC interoperability and international capital controls. CBDCs can make social protection and emergency payments more efficient and targetable, which are particularly useful in times of crises. Moreover, CBDC will put more demand on energy and communications infrastructure. If not carefully analyzed and managed, the amount and source of energy could prove to be environmentally costly.

New opportunities to influence currency and payment systems are opening up, creating room for improvement. The greater granularity of transaction data may help central banks and governments better manage monetary stability – to be balanced with unnecessary access into transaction privacy. But CBDC could also create new sources of financial volatility, at least in the short term, where capital flight and bank runs can contribute to instability.

Socio-cultural reactions to fast and digital banking may alter how community and household money is stored

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[2] Some countries are researching a Universal Access Device (UAD) which could look like a Near-Field Communication (NFC) enabled credit card and allow both online and offline transacting.

[3] ITU Statistics, consulted on 31 March 2021, at https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

[4] UNCTAD Technology and Innovation Report, 2021, available at unctad.org/system/files/official-document/tir2020_en.pdf

and transferred. CBDCs will likely impact formal and informal economies differently, altering which and to what extent work is regulated. Entrepreneurship and innovation trends may speed up with easier access to start-up financing. Digital transactions may facilitate access to MSME trade finance but also complicate cross-border trade for those that have not yet digitalized their operations. New financial actors may emerge depending on the CBDC architecture, and the mandates of existing actors may change, such as central banks managing CBDC digital identities. Without proper design, CBDCs can be a new source of inequalities and discrimination.

A national CBDC will have broad international effects

The decision to pursue a CBDC is the sovereign prerogative of each nation. However, given the interconnectedness of our markets, as more countries issue CBDC, it is likely that trade, value chains, investments, currency competition, remittances, and tourism trends, will pressure other central banks to adopt CBDC or authorize interactions with other CBDCs. Macro-economic impacts of CBDC need further analysis, and certainly without guiding standards for CBDCs pursued collaboratively among advanced and developing nations, these impacts may jeopardize any opportunity.

Digital currency provides also new opportunities for illicit cross-border financial activity – money laundering, terrorist financing, fraud and other criminal activity. Privacy, anonymity, and CBDC account controls can be designed so that central banks can deter and enforce action against criminal activities; this will need to be balanced against consumer privacy rights for CBDC users. Involving a wide range of stakeholders in the CBDC design phase may help to achieve this balance at the outset.

Finally, with limited domestic expertise, developing countries may be forced to rely on out-of-country expertise and not be able to *bring the particularities and needs of developing countries to bear on discussion. Developing countries need capacity building to actively participate in CBDC research, technology design, and standards development. Stronger developing country and emerging economy voices are also required at international CBDC forums.*

The way forward

This paper presents a high-level view of how digital currencies may impact financial inclusion, and sustainable development more broadly. The nature of these impacts and opportunities it offers heavily depends on the design choices and standards; therefore, *CBDCs should be pursued in a way that reflects developing countries' specific contexts, including their financial and institutional capacity and level of development.*

Moreover, while the international community struggles to rebuild better from the pandemic, CBDCs should be explored as a new tool to foster better recoveries; it must be designed inclusively or risk widening the gender, digital and inequality divides.

Three objectives must be reached in the way forward:

1. In-depth, multi-country research to better understand the implications and impacts of digital currencies, particularly for vulnerable countries and populations. Initial research questions could include:
    a. How can CBDC be designed for meaningful inclusion?
    b. What will CBDCs mean for MSMEs' domestic and international trade facilitation, including women-led MSMEs?
    c. If CBDC becomes mainstream, what, if any, are the environmental costs?
    d. Can CBDCs provide a pathway to better financial reward for labor and know-how?
    e. What will CBDC mean for the millions of people in the informal economies?
2. Far-reaching advocacy and awareness raising around digital currencies – including risks, appropriate usage, and opportunities;
3. Development of a multilateral platform to foster reflections about the design of CBDCs that include all stakeholders, especially those who risk suffering the most from CBDCs.

Fortunately, there is no need to create new structures or venues to achieve the above. The UN ECOSOC Commission on Science and Technology for Development (CSTD) offers such an intergovernmental platform to review and monitor the design of feature sets and regulatory requirements for CBDCs. It could create a dedicated working group to monitor and support CBDC development and capacity building needs. The UN financing for development in the COVID-19 era and beyond under the leadership of the UNSG and the Canada and Jamaica could reflect on these findings and offer policy options.

Automating the Achievement of SDGs: Robotics Enabling & Inhibiting the Accomplishment of the SDGs

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Abstract

The role of robotics is rapidly growing in importance in the particular non-industrial application domains, affecting society, economy and the environment. Robot systems are typically developed to address a specific technical, service-type or economical need, but often their broader impact is insufficiently investigated, if at all. For robots to play a beneficial role at society-level in the future, it is important to identify the mainstream directions in the field that enable the UN Sustainable Development Goals (SDGs), and encourage their development. Similarly, it is required to understand the negative impacts some applications can have on the achievement of the SDGs, and to ensure societies have the ability to prevent or mitigate them. Inspired by an exploration of the role of artificial intelligence in achieving the SDGs, this paper presents a preliminary version of a consensus-based expert elicitation process on the role of robots - as enabler or inhibitor - for a more sustainable future. For every SDG, the authors were able to identify potential positive and negative impacts of robotics. It remains difficult, though, to sketch a simple and comprehensive overview of the different ways in which robotic applications can unfold (direct or indirect) impact. Existing projects and studies are not intuitively comparable because they take many different directions and are not at the same level of abstraction, technological readiness, or implementation. Derived from the findings, recommendations on future policy developments are considered.

Introduction

In 2015, 93 countries agreed to establish the United Nations Sustainable Development Goals (SDGs). They are a framework of recommendations and principles to achieve a better and more sustainable future for all. After the Millennium Development Goals (MDGs), they address global challenges, such as poverty, inequality, climate, environmental degradation, prosperity, peace, and justice.

To facilitate the realization of these standards, member states rely on different approaches and manifestations of innovations. Besides well-known methods from governmental toolboxes, like political and regulatory improvements or the stakeholder-driven discourse about the establishment of new governance frameworks, fostering and leveraging technological progress becomes more and more crucial to address the increasingly complex problems tomorrow's world and its civilization will be facing. Albeit predicting the future is impossible, the analysis of the so-called 'Megatrends' [1] provides one commonly accepted method for estimating driving forces that will have an impact on the whole planet earth and humanity over the next 15 to 25 years. Extrapolating these trends, it is possible to make predictions for future needs, developments of future markets and overall requirements for technological innovation. Mobility, globalization, global warming, over-ageing society, urbanization, digital life / connectivity, individualization, and orientation towards a healthy lifestyle are an often-cited subset of megatrends that will heavily influence the evolution of disruptive technologies, such as robotics and automation [2].

Currently, the world is experiencing the peak of the digitalization wave. But the next, maybe even bigger disruption is already afoot: Robotics and Automation. Riding on the wings of Artificial Intelligence, they will permeate all areas of our living realm. Over the next 50 years, they will have at least as much impact on society and our world as the internet and mainstream IT have unfurled over the last five decades. Subsequently, our grandchildren will grow up as the first "Generation 'R'" of "Robotic Natives" – in daily contact with these technologies – and will often rely on the development of digital technologies [3]. Today, though, they still remain limited in their potential impact (e.g., because of the important associated costs, or the lack of available devices in critical situations, for instance during the COVID-19 crisis). It is very possible that robotics will play a key role in the implementation of international strategies (e.g., the Great Reset initiative of the World Economic Forum) to help shape the recovery and rebuild society and the economy in a more sustainable fashion.

Robotics & SDGs

The progress of robotics and its increasingly broad adoption will be comparable to the rapid dissemination of mainstream computer technology the world has seen in the past. It will even follow similar waves (Miniaturization, Mobilization, Ubiquitiousness and Pervasiveness) [3]. As promising and beneficial it could be, its development also comes with its own critical systemic, environmental, and social challenges [4, 5, 6]. All hopes need to be reconsidered in the light of the important limitations and ethical dilemmas raised using robotics to achieve the SDGs. Our objective is to identify, define, analyze, and disentangle the various impacts that its development may generate in relation to the SDGs.

To do so, it is necessary to combine the experience of the robotics community with the expertise of multidisciplinary specialists in fields such as economics, sociology, law, , environment, biology, design, among others (e.g., in [7]). The authors therefore developed a methodology inspired by a study by Vinuesa et al. 2020 (in Nature Communications) [8] on the role of AI as either an enabler or an inhibitor in achieving the SDGs. Vinuesa's approach can be summarized as a consensus-based expert elicitation process.

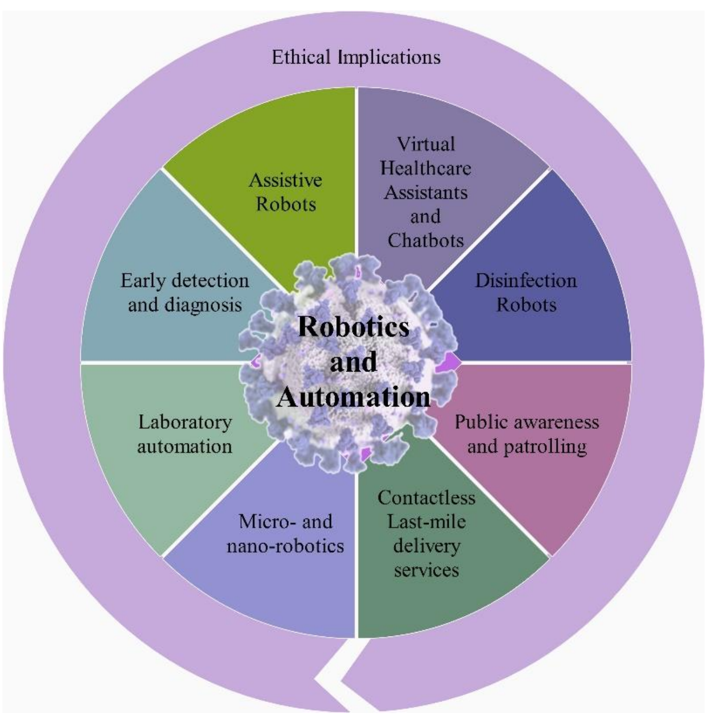

Figure 1 – The societal level benefit of robotic technologies has clearly been demonstrated recently, when numerous robot solutions arose to diagnose and treat COVID-19, fight the coronavirus pandemic and alleviate their dire consequences. Such functions relate to SDG 3,4,8,11,15 [13].

In addition, the authors of the present study will consult the robotics community through a dedicated workshop at a major conference in Robotics [IROS2021] in the objective of leveraging the collective experience and intelligence of the robotics community. The results of this study could be an important tool for politicians, civil society and trade unions. They can be used as a basis for stakeholders to establish the guidelines and governance frameworks [10, 11] that will allow robotics to contribute to a more sustainable world.

Robots as Enablers & Inhibitors for SDGs

Robots can be regarded as physical entities with sense-think-act capabilities to work in the physical world. The authors used the definition as stated in the Encyclopedia of Robotics: "A robot is a complex mechatronic system enabled with electronics, sensors, actuators and software, executing tasks with a certain degree of autonomy. It may be pre-programmed, teleoperated or carrying out computations to make decisions " [12].

Robots offer a wide range of means to help achieve the SDGs. For instance, Robotics can enable innovative and effective learning methods and open new avenues for pedagogy to improve the quality of education in both developed and developing countries. This quality education is a key driver of economic growth and a main catalyst for poverty eradication and sustainable development. Robotics also has broad-ranging impacts on industry to ameliorate work conditions, increase productivity and reliability while reducing waste and improving quality and competitiveness. By using drones for search and rescue missions in case of natural disasters, or by delivering food in war zones with self-driving trucks, robots could reduce the impact of such catastrophes. Robots can be used to monitor environmental changes in air, land and water, and may allow a better understanding and preservation of ecosystems. Precision agriculture and smart farming can increase productivity and reduce waste of food, thus helping to provide food security. Similarly, robots will increase the overall productivity in many industries by automating tedious tasks, thus reducing the price of goods and the risk of work-related injuries. They could improve access to transportation and healthcare and augment the quality of life of elderly and physically challenged individuals. Robots as part of space exploration programs push the boundaries of human knowledge and are a formidable inspiration for people of all ages to learn about science, technology, engineering, and mathematics (STEM).

The most recent and prominent example is the use or robotics to fight the current pandemic: Since the outbreak of the novel coronavirus (SARS-CoV-2) and its highly contagious disease COVID-19, robotics communities quickly mobilized and gathered to offer solutions ranging from early detection and diagnosis solutions, assistive and disinfection robots, robots used for public awareness and patrolling, contactless last-mile delivery services, to lab automation. Robots perform many assistive tasks during the pandemic to mitigate the risk to healthcare professionals. Applications of these robots include, but are not limited to, helping medical staff avoid infection from virus patients, early detection and diagnosis, medical care, nursing, patient monitoring, performing lab work, cooking and serving medication, meal delivery to patients in isolation wards, indoor and outdoor disinfection and public awareness and patrolling. Contactless last-mile delivery has witnessed an unprecedented importance and a sharp demand rise during the pandemic to ensure sufficient social distance between medical staff and patients in the hospitals and between people during delivery. Several systems have been deployed and tested during the pandemic for medical supplies, medications, food, grocery and other goods. Various research labs, businesses and start-ups have innovatively changed their work goals to use robotics and automation to speed up the quest for a cure against COVID-19. Vaccine discovery and production require massive amounts of experiments and processes. Robots can be used in laboratories to automate repetitive and time-consuming tasks such as sample processing, goods delivery, and for conducting experiments [13, 14].

But robots may also impede progress towards the SDGs. First, they can be abused and involved in major ethical issues (e.g., the increase of surveillance, the use of robots by oppressive regimes, a potential lack of acceptability within the general population, issues regarding data privacy and further augmenting the digital divide) [4, 5]. Additionally, robotization of industries will cause routine manual and routine cognitive job losses. This will primarily affect workers with low education and countries who do not have the means to invest in such technology or to educate a workforce able to benefit from this process. Given the macroeconomic situation of most of the developing countries and the high initial cost of adopting robotics technologies, there are even further challenges such as the overproduction-underemployment dilemma. There is a common misconception about robotics and automation and the lack of highly qualified personnel able to deal with these technologies. In order to ensure a higher level of acceptance and adoption of robotics and automation in the society, education on these technologies is crucial. Similar inequalities can be seen in the use of robots in agriculture, which can prevent small farmers from competing with multinationals, thus enhancing urban exodus and threatening food sovereignty. In addition, robots are often manufactured containing rare-earth materials and produce e-waste, which causes an inherent danger to the environment if not dealt with properly. Robots consume energy to sense, think and act and are commonly much less energy efficient compared to human workers. They may also ease the feasibility of projects which may have damaging consequences on the ecosystems, such as in the exploitation of natural resources: fossil fuel extraction, forestry, mining, etc. Furthermore, they can delay structural changes needed to address global warming (e.g., with the rise of autonomous cars) or encourage over-consumption of products (e.g., autonomous drone delivery systems).

The Promising but Ambivalent Role of Robotics in the Achievement of the SDGs

Nearly for every SDG, the authors were able to identify potential positive and negative impacts of robotics. It tends to show the dual nature of Robotics' contribution towards the SDGs - as is inherently applicable to all disruptive technologies [5, 15, 16]. A complete, more digestible, and graphically enhanced overview will be made available in the final publication later this year.

However, it remains difficult to have a thorough overview of the different ways robotic applications can have an impact. We need a deeper understanding of the challenges at stake. Robotics will have a great impact on our society and economy, but also bring with them complex challenges. Some believe robots are showing us the way towards a utopia, whilst others predict doom-laden scenarios. Nonetheless, it seems evident, that our grandchildren will grow up in daily contact with different forms of automation technologies, making them the first Robotic Natives – which leaves us the last generation of Robotic Immigrants. With our very analogue migration background, we will have to overcome some challenges and struggles in accepting, adopting, and embracing robotics.

The enablers or inhibitors are inseparably intertwined with peoples' hopes and fears. But it is us, humans, who invent and develop technologies. We have the duty and power to shape our own future. The professional work experience, skills and insights of the robotics community (and of interdisciplinary experts from a wide array of disciplines) can, should and will have a catalytic impact.

*Figure 2 – Symbolic representation of impact of robotics o**n the SDGs***

Selection of Empirical Facts & Issues

This bullet list provides a first (incomplete) selection of the empirical facts and issues that were identified by our research:

- Robotics will have an increasing role in critical situations, from supporting healthcare workers during COVID-19, to help in sensitive or dangerous operations (e.g., minesweeping, nuclear waste disposal) [1, 2, 4, 7, 13].
- Robotics could leverage important health inequalities, for instance by democratizing surgery (e.g., by providing universal access to high quality surgical and medical care on a global scale), with telesurgery in the past and now with autonomous diagnostic and treatment delivery options [14].
- To achieve the SDGs, robotics will play an active role within public, academic, and private initiatives [7, 8, 9].
- Robotics and automation can contribute to optimize complex processes (e.g., food production), to improve difficult tasks (e.g., cleaning waste, pollution, water), to monitor the effect of climate change and human activity (e.g., with drones or autonomous sensors)[1, 2, 4, 7, 8, 9].
- However, robotics has an important carbon footprint, uses vast amounts of energy, needs rare materials, generates large quantities of waste, and can oftentimes be outdated fast because of technical progress (e.g., as commercial products) [4, 5, 6, 10].
- Furthermore, robotics sometimes remains experimental and limited, not deployed at a large scale, and raise critical ethical and social issues (e.g., from increasing surveillance to accelerating job losses)[4, 5, 6, 10, 11, 16].
- To avoid being an empty promise, Robotics needs to better document its own impact and challenges, while contributing to achieve SDGs [5, 6, 10, 11].
- Technologies like robotics and AI must be transparent, explainable an understandable [5, 6, 10]

Policy Recommendations

Derived from our findings, we want to recommend these ideas on future policy development for consideration:

- International organizations, such as the United Nations, should provide specific (sub-)goals for each domain (e.g., robotics) to better translate the 17 SDGs in different fields of practice.

- International organizations in Robotics (e.g., IEEE, euRobotics, IFR, …) should be encouraged to:
  - analyze and document at a large scale the impact of robotics to the environment (subfield by subfield).
  - highlight each year their most efficient and evidence-based contributions to fight climate change and achieve other SDGs.
  - develop and provide tools (e.g., checklists, practical guidelines, frameworks, governance) to help researchers, engineers, public decisionmakers and entrepreneurs to better integrate SDGs within their projects and roadmaps.
  - develop and provide tools to help researchers, engineers, public decisionmakers and entrepreneurs document and calculate the impact of their projects on the environment (e.g., carbon foot-print calculators, lifecycle methodologies) and – if possible – society
  - help to explain their technologies and development progress as transparently and realistically as possible to foster public understanding and acceptance.
- International conferences in Robotics should require submitters to explain a) the environmental and b) societal impact of their projects, as well as c) the potential contributions of their projects to the SDGs.

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The Future of Urban Design

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Human security and well-being for urban design

The UNDP states that human security threats have shifted from catastrophic threats such as war to daily worries such as jobs, income, health, the environment and crime. The targets have become global, not just individual, local or national[1]. The Commission on Human Security, chaired by Sadako Ogata and Amartya Sen, has pointed out that human security is a public good and that nations and the international community need to work together to protect and assist people in vulnerable situations[2]. In 2012, UN Resolution A/RES/66/290 defined *human security* as "the right of people to live in freedom and dignity, free from poverty and despair[3]."

There has been an outbreak of COVID-19, which in its typical form threatens human security[4]. This outbreak was primarily caused by the rapid spread of a highly contagious virus among globally linked cities, which led to widespread and prolonged lockdowns in cities worldwide. According to the United Nations, this pandemic led to a rise in the unemployment rate and the first increase in global poverty since 1998.

Urban areas developed rapidly in the 20th century, and according to the DESA, 68% of the world's population, or 6.7 billion people, are expected to live in urban areas by 2050[5]. Furthermore, the NUA2020[6] shows that living in cities contributes to economic prosperity, environmental conservation and social equality. Therefore, it is urgent to consider how urban areas can develop sustainably given the impact of infectious diseases to ensure human security. Koizumi (2015)[7] has pointed out that it is also essential to consider the well-being of residents and ensure human security in cities, as many mental health problems were caused by long-term lockdowns. In this session, we propose a new urban design that enables sustainable economic development while ensuring comfort during normal times and Decent Living Standards (DLS)[8] during outbreaks[9].

New localization in a new normal era based on Multi-AI

Given our experience in trying to avoid the spread of COVID-19, it has become clear that population density is not an issue, but overcrowding and excessive congestion are crucial. Therefore, pandemics can be contained even in urban areas by ensuring hygiene in restaurants, workplaces and public transportation. In other words, it is critical for a sustainable urban system to manage human behavior at a sufficient level during a necessary period. In this context, a new regional design is needed to avoid affecting society and the economy in a globally linked metropolitan area. Fortunately, recent developments in AI and IoT can guide people to the appropriate behavior both in ordinary and emergent situations[10, 11].

Therefore, a Multi-AI system would minimize the infection risk by ensuring human comfort and a decent living standard. The system includes technologies to a) detect the individual coordinates of smartphones, b) estimate one's physical and mental condition from vital data and c) estimate comfort levels from everyday facial expressions using IoT technologies.

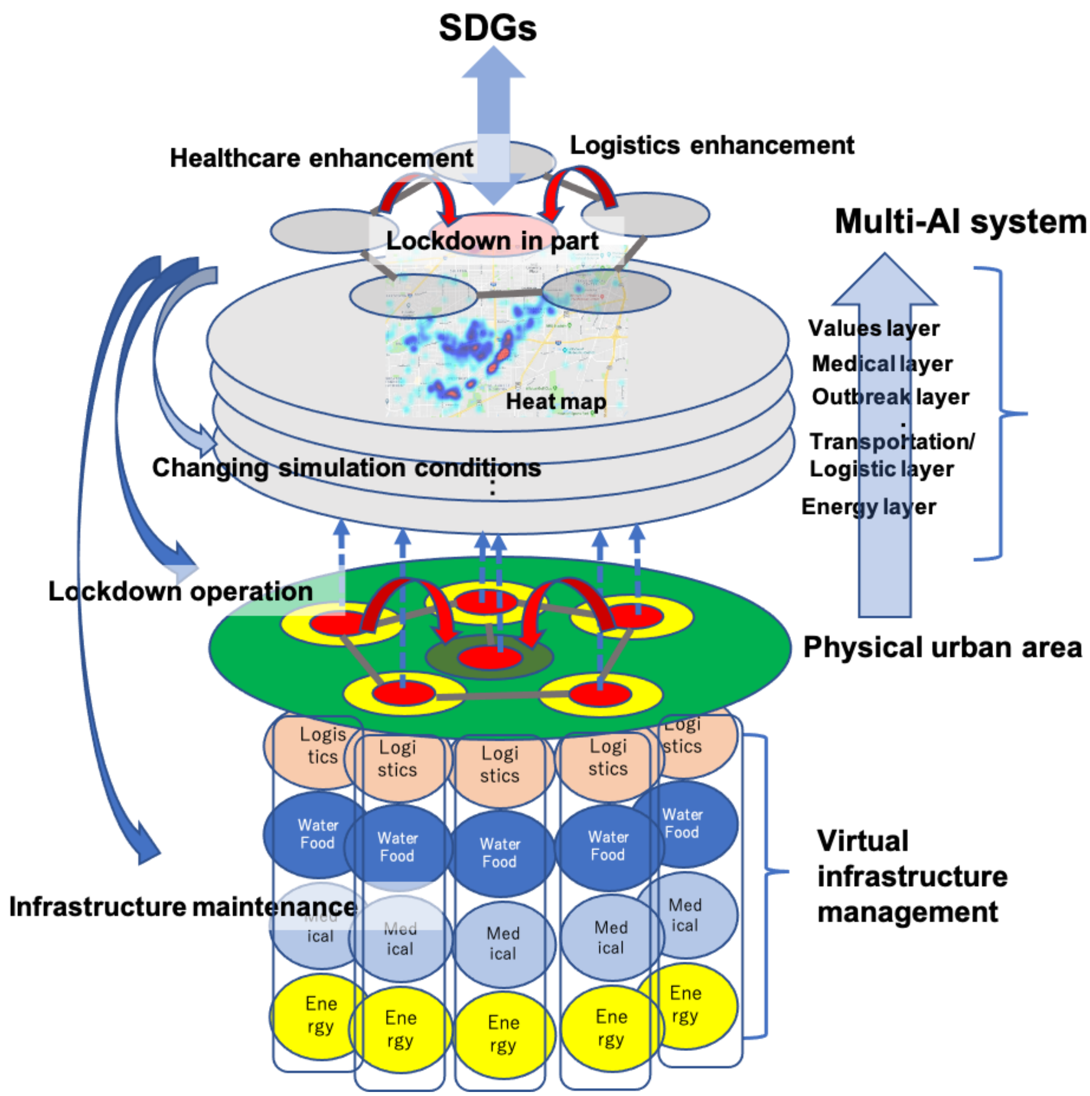
Furthermore, this system can simultaneously consider the situation of both various individuals and urban clusters based on its open platform. The platform has layers to make a heat map of the geographic distribution of infectious diseases obtained from sewer PCR (polymerase chain reaction) and of city services such as urban traffic, logistics, water, food and energy supply.

In executing this system, it is expected that humans would take prompt countermeasures if AI could analyze the situation of the layers instantly with humans then providing comprehensive and multilateral feedback.

Specifically, this Multi-AI network city [12] (Fig. 1) clusters a living area of 10,000–30,000 people to limit the lockdown area by flexibly switching the lockdown areas given the infection distributions in the region.

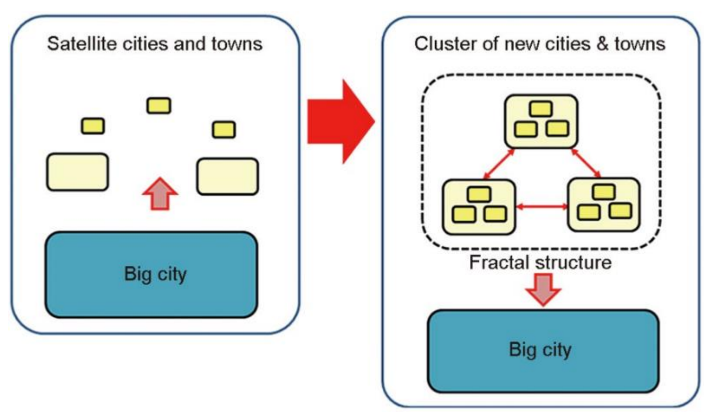
Regarding the dimension of a cluster, there are various viewpoints. One perspective defines a cluster as an elementary and/or junior high school district, which is typically 5,000–10,000 people. Another perspective defines an area as a 15–20 minute one-way walk from a living area to community services. Although the dimension is important to withstand a long-term lockdown, the cluster scale is tentatively determined to be 10,000–30,000 people in this study. Further research is necessary to find a suitable lockdown unit to protect against the spread of infectious diseases.

Figure 1. Concept of Multi-AI networked cities[12]



On the other hand, it takes 100 years to physically relocate all the buildings and infrastructure of a current city. For this reason, the aforementioned Multi-AI network city is based on the concept shown in Figure 2. In this figure, the city area is divided into clusters to ensure well-being. Concluding this chapter, the cluster network to connect communities in cyberspace can reduce humans' mental burden from the physical restrictions due to the pandemic, climate change and natural disasters. In this meaning, the highly autonomous well-being clusters are our practical goal toward an AI-human collaboration era.

Figure 2. A new urbanization concept of holistic city clusters



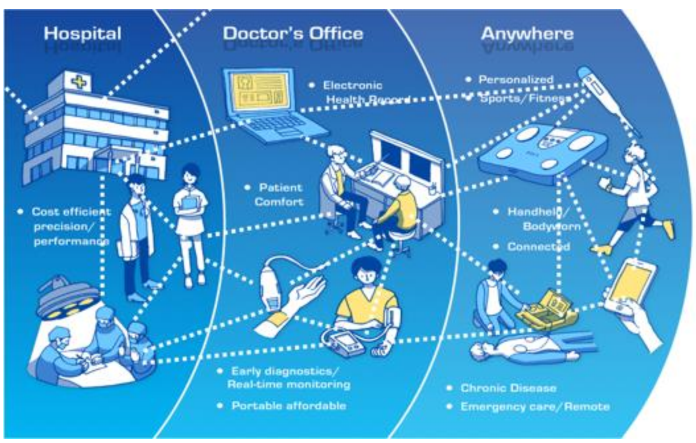
Source: Koizumi (2015)[7]. *Note:* In the original paper, a realistic urban structure was imagined, but we propose that it be virtualized.

Toward the achievement of multimodal AI

The key to realizing this system lies in the development of a multimodal AI that interlinks a wide variety of input data monitored in urban areas. Although there are many challenges in developing this multimodal AI, the current situation in the medical field can help us understand the road map for its development.

In Japan, during the pandemic, the IT and digitalization of information sharing in healthcare were insufficient as the number of affected people was communicated by fax, exposing the level of information literacy in healthcare. This is because the medical information network has continued to expand its implementation on an ad hoc basis by limiting the system's information, and the expansion of functions to share new information requires high costs. This inefficiency in information sharing further leads to delays in intra-hospital/regional medical logistics (reallocation of medical resources), delays in changing the medical system according to the pandemic level and difficulties in cooperation between central medical institutions and regional medical facilities. The development of systems and platforms that can respond immediately to various types of information sharing is an essential and urgent issue.

Figure 3 Autonomous network system with multimodal AI in the medical field



In fact, few studies have been directed at extending AI capabilities for comprehensive well-being through generic autonomic auto-networking of heterogeneous AI[13]. In a multimodal AI system, in addition to the inductive inference function, the AI will have an autonomous automatic networking function by deductive inference. In doing so, a multimodal AI system that flexibly performs pervasive data sharing and data processing will be created. This system will be able to handle the data and processing of complex systems with diversity, multiple faces, non-uniform distribution in space and interactions[14], and will be able to automatically share and process complex data with an order of magnitude greater efficiency (Fig. 3).

Recommendations for the future of urban design

The pandemic has led to several engineers returning to the basics to guide our way of thinking. For example, does materialistic prosperity ensure happiness or well-being? What is most important to us as human beings? What is the destination of engineering—the true objective of engineering? We have realized that engineers are responsible for working together across disciplines to build a resilient and sustainable system that will prevent an entire city from disrupting at once—regardless of the situation.

In this report, we have focused mainly on the system to be controlled. However, progress in technological development, such as sensing and monitoring technology and hardware development to realize a response, will also be necessary. While careful consideration must be given to privacy and data protection, by integrating the development of hardware and the software to utilize it, more effective and efficient functions can be achieved.

The challenge with the pandemic is to break the trade-off between comfort and human security through STI, and to realize a city that can serve as the basis for resolving such a trade-off, and we hope that this proposal will help to achieve this goal.

1) Create a human-centered city that pursues well-being and aims to ensure comfort in peacetime and decent living standards during outbreaks.
2) Realize a city that ensures human security and well-being under any circumstances by achieving an autonomous and decentralized urban cluster structure without disrupting the current urban structure.
3) Develop a system to autonomously manage an entire city with the cooperation of humans and AI by connecting diverse data between urban clusters.

Acknowledgement

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Machine learning to improve disaster assessment

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Abstract

After a sudden onset disaster, first responders are in a race against time to get detailed damage assessments and prioritize relief for the communities most deeply affected. Recent advances in the field of machine learning (ML), coupled with drone and satellite operations, are making more accurate analyses of high-resolution imagery available more quickly. This brief summarizes experiences of the World Food Programme (WFP) in supporting governments and communities with artificial intelligence (AI) and ML systems in Mozambique and Lebanon. It outlines the lessons learned from preparedness efforts, such as prepositioning equipment and training, and the need for more robust data protocols, governance and collaboration to maximize the benefits of these Fourth Industrial Revolution technologies.

How can machine learning support disaster mapping?

Disaster response relies on detailed, location-specific data. This makes impact maps a strategic asset for first responders, who rely on them to allocate resources and for post-disaster recovery initiatives. The trend to more frequent and extreme weather events, the increased urbanization of disasters, and donor expectations of targeted assistance implies that stakeholders' need for fast access to and analysis of high-resolution, detailed information will continue.

Previously, humanitarian agencies relied on information from satellite images, or from photographs taken with cell phones, which was manually extracted and analyzed. This could often be a time-consuming and error-prone process (Kerle, 2010). Advances in ML and the availability of very high-resolution imagery from drones or satellites offer the opportunity to quickly mass-produce detailed and accurate impact maps (Cooner, Shao & Campbell, 2016).

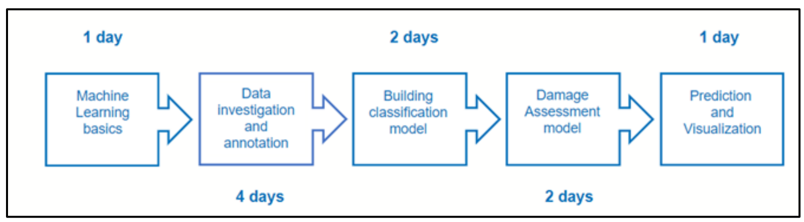
In collaboration with private sector partners and research institutions, WFP is developing and testing a wide range of projects which leverage ML, including to assess crop damage, monitor landscape changes, and detect roads from satellite images. This brief will focus on two complementary ML projects to assess building damage: DEEP, which processes both satellite and drone imagery; and SKAI, which analyzes satellite imagery.

Lessons learned from WFP deployments

DEEP uses satellite imagery or drones to capture imagery, which is then processed on a standard gaming-spec laptop computer. It offers a plug-and-play package that is easy to use in field settings by WFP and its partners. The project began in 2019 with a series of workshops for first responders and drone specialists.

WFP prepositioned drones with its Regional Bureau in Johannesburg and trained the Mozambique Natural Disaster Management Agency (INGD). This enabled DEEP to be deployed in the aftermath of Cyclones Idai and Kenneth to support capacity building with the University of Mozambique and INGD.

Figure 1. Capacity building workshop workflow for DEEP.



Source: WFP

Where damage assessment previously took two weeks, DEEP can capture required imagery in 10 minutes and the building damage classification is 85% accurate. The INGD was the primary client for the data, but it was also used by other humanitarian agencies including the UN Food and Agriculture Organization (FAO).

With Google Research, WFP developed SKAI, which provides an assessment of building damage within 24 hours of receiving satellite images using ML to automate the process (Cooner et al., 2016). By training models to distinguish between damaged and undamaged buildings using expert-labeled images of past disasters, entire cities can be analyzed in a matter of minutes by modern data centers.

Figure 2. A DEEP disaster map.

Source: World Food Programme. Note: To the right is the output of the ML assessment. Red signifies destroyed buildings; purple signifies intact structures.

SKAI applies 'semi-supervised' ML, which requires only 10% of the dataset to be labeled and used as training data in comparison to 'fully supervised' learning methods require at least 50% data to be labeled as training data (Lee et al., 2020).

Since its inception, SKAI has been used in many disasters, including the Haiti earthquake in 2010, the armed conflict in Syria in 2016 (Xu et al., 2019), the Santa Rosa wildfire in 2017 (Gupta et al., 2019) and the Beirut Explosion in 2020. In Fiji, SKAI was used following Cyclone Yasa in 2021, and local actors helped label images, including the government and the local GIS community. The turnaround time depends on the type of disaster, with ML assessments proving most valuable for large areas (e.g. entire cities) and consistently 80% more accurate than manual assessments, which are still faster for small areas with less than 5,000 buildings.

WFP's experience with SKAI and DEEP show that ML can help produce highly accurate maps in a fraction of the time that manual processes would take, and that collaborating and building capacity with local actors not only improves disaster preparedness and response, but also the trust between people and machine learning.

Challenges in Applying Machine Learning in Damage Assessments

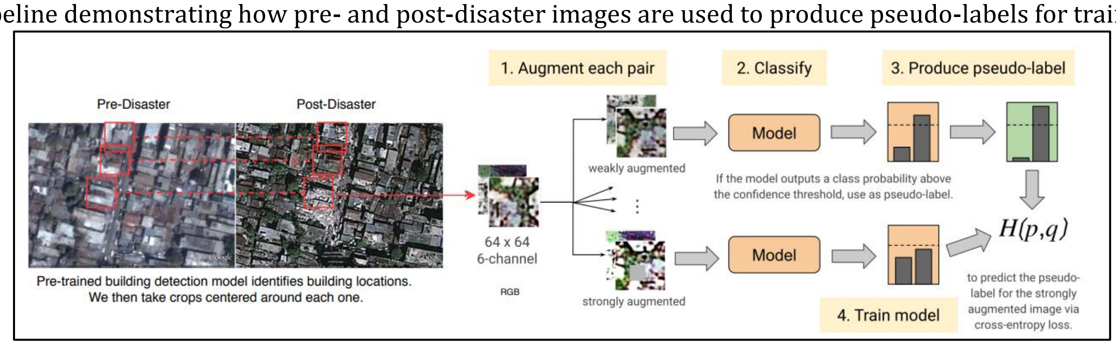
While both projects demonstrate the promise of this technology, some challenges were also identified that need to be considered as the technology is used more widely.

Not a cure-all. ML is not always the best solution, with SKAI showing it only adds value when used to assess larger areas, with the damage visible from satellite images. Therefore, we need to learn to apply a mix of manual and ML approaches using various types of images.

Limited access to data. Obtaining data throughout the training and testing cycles is one of the main bottlenecks.

Limited training datasets. Available datasets (xDB and UNOSAT) are extremely useful, but insufficient to train ML models applicable to all disaster types in all geographical areas.

Figure 3. Pipeline demonstrating how pre- and post-disaster images are used to produce pseudo-labels for training for SKAI.



Source: WFP

Nonstandard labeling of damage in training datasets. xDB uses a four points scale for damage, while UNOSAT uses a five-point scale. The labeling is incoherent and there is uncertainty as to what standard to follow. In SKAI's case, buildings are classified as 0 for undamaged and 1 for damaged, which provides high-level estimates of t number and location of people affected, but does not classify the damage in detail.

High cost of very high-resolution imagery. To be effective, a machine needs to extract granular information from satellite images. The cost of this is a hurdle for local actors and international humanitarian agencies, which means the data pipeline is not updated with the optimum frequency and or granularity.

Operationalizing and scaling machine learning assessments. The path to integrate and scale this technology needs to be discussed, and synergies with other humanitarian data streams explored.

Humans in the machine learning loop. Humans are needed to label training data, validate and continuously fine-tune the model outputs. WFP is discussing who could or should be labeling images and how ground truth data can inform the ML algorithm in the most time efficient way.

Machine learning in the broader system. Humanitarian stakeholders will need to agree on when and how to deploy a specific machine learning model, what a reasonable level of accuracy would be for different phases of the response and how to manage overlaps in assessments by different organizations

Data Governance. Arrangements are needed to balance data protection and sharing of information for both humanitarian and research purposes.

The way forward

DEEP and SKAI show that capabilities exist to use ML models for fast, accurate and credible damage assessments. The models will grow more powerful as more real-life data are collected and used for training purposes. The UN Secretary-General's Roadmap for Digital Cooperation highlights the need for greater coordination in capacity-building and developing common standards to guide the private and public sectors in ensuring more data become available as digital public goods, while respecting privacy and confidentiality. In that context, there are four main areas to consider for scaling these methods and benefits for governments and agencies.

Policy on sharing protocol and resources to generate, manage, maintain, and govern data pipelines. Data to ML models is like fuel to cars. WFP calls for a policy that encourages responsible data sharing along the full ML cycle to enable collaboration amongst different organizations. A pooled fund is needed to purchase and/or share satellite images and derivative products, with shared resources to retain and maintain data pipelines. The sector needs shared data governance rules, which can be applied by both public and private sectors. This echoes calls for a global data commons for humanitarian response (see UNGP).

Machine-learning first humanitarian assessments? Humanitarian responses previously involved a series of complex and collaborative operations using manually collected data. As the technology matures, the process will gradually transition into a machine-learning-first humanitarian assessment and response process. WFP calls for strong policies to guide UN bodies, local non-profit organizations, international and regional governments in understanding, using, and building trust between people and machines for humanitarian response.

Public-private partnerships for disaster assessments. There is much to be gained by enabling the deployment of ML models that belong to private companies. WFP calls for increased collaboration to find a way of working that allows privately developed disaster assessment models to be used for free by humanitarians, with the intellectual property continuing to be owned by the company.

Invest in local capacities. DEEP has shown that investing in local capacity ensures an adequate level of preparedness to quickly deploy ML when the need arises. WFP calls for more collaborative efforts to train local drone operators and ML analysts.

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Virtual reality to strengthen natural disaster management

Gözde Akarsu, Eeke Bastiaansen, Marieke Holownia, Katharina Seper (Wageningen University, the Netherlands)

Key messages

Virtual Reality proves itself to be instrumental in all three phases of natural disaster management: preparedness, response and recovery by bridging the gap between knowledge and action.

Even though some barriers, such as price and user experience, are projected to be improved or even overcome in the future, proper action still needs to be taken to ensure effective and efficient implementation in natural disaster management.

Policy- and decision-makers are able to influence the future development of Virtual Reality in natural disaster management: the described scenarios and key recommendations give guidance to do so.

Introduction

Due to the growing occurrence of natural disasters all around the world, there is an increasing need for more efficient and effective natural disaster management (NDM). NDM is the systematic process to save human lives, divided in pre-, during-, and post-disaster actions.[1] However, a gap between knowledge and action exists in all different phases of NDM.[2] Firstly, due to the nature of natural disasters, it is impossible to prepare and train under real-life conditions, limiting the learning experience of first-responders, civilians and city-planners. Next, during disasters, communication is key to reach people and to arrive at locations in most need of assistance. Lastly, as a result of destruction and devastation, it becomes difficult to visualize possible pathways to recovery, since danger levels are still high, and resources are scattered. VR poses a solution to all these problems and its application in NDM will be essential in the future. Moreover, VR cannot be ignored anymore: it has grown exponentially over multiple markets and is projected to have a worldwide revenue of USD 40 billion by 2024.[3,4]

Current Use

Already, VR is used to simulate floods, earthquakes, wildfires and hurricanes in all three phases of NDM.[5–9] In preparedness, VR is used for simulations, training, early warning systems, monitoring, and awareness raising.[10–22] It can be used together with smart systems based on artificial neural networks and drones to improve prediction of forest fires and support coordination on the ground.[8] Further, VR is used for real-time response during natural disasters via information systems, for example forecasting and visualization of wildfires in virtual GIS.[10,11,21] VR recreates what is happening in real time by combining the location of human and material resources with the propagation of wildfire, enhancing decision-making on the ground.[7] Finally, for disaster recovery, VR has proven essential for the reconstruction of buildings, as it provides a safe environment to recreate and illustrate the possible pathways to recovery.[11,12,14] In general, VR proves crucial when a situation is Dangerous, Impossible, Counter-productive, or Expensive (DICE), which is the case with most natural disasters.[13]

Benefits

Preparedness

With VR first responders and citizens can be trained in situations that cannot be simulated in any other way.[17,22] Simulations create a sense of confidence, give first-responders space to practice and make mistakes, and improve their reactions during a disaster.[11,14,17,23–25] Citizens, including vulnerable communities, can also be trained. For example, by showing them possible evacuation routes.[20,23,24,26] Through training, their ability to evaluate risks increases and their reaction time reduces.[19] Furthermore, many people are unaware of the risks of natural disasters.[11,15,17,19] VR can, through its immersive experience, create consciousness on urgency to act.[15] Additionally, natural disasters can be simulated in existing locations, and through this recreation, fragile infrastructure and danger zones can be pointed out.[5,12] This new way of risk assessment can directly determine how many resources the city and community need to improve resilience for future disasters, which is one of the most effective long-term strategies.[12,18,26] Furthermore, VR offers collaborative immersive spaces which allow different experts worldwide to work together in the same virtual environment, creating more enhanced and coordinated solutions.[5,12,17,19,22]

Response

Through the training of first responders, the quality of response during natural disasters improves. Muscle memory is developed because their mind and body have been in the situation before.[15,17] Through the improved orientation in VR and the experience of first responders, more knowledge about possible natural disaster scenarios is gathered. This can create better decision making on how and where to respond. Furthermore, VR enhances the understanding of different elements in infrastructure, such as power and waterlines, consequently improving decision making without the risk of neglecting these elements.[27] Through technologies such as VR-glasses, better response during a natural disaster is possible by directly sending data to people in command who can, in turn, develop a more accurate response.[10] Another example is the tracking of wildfires with drones and 360° cameras, which, help to develop a real time algorithm to locate the fire.[7,20]

Recovery

Through the enhancement of preparedness and response, also the recovery phase improves and the time to return to the initial state decreases significantly.[19] Besides, the enhanced visualization of the aftermath facilitates recovery by pointing out the most critically damaged areas and identifying missing infrastructure to create routes of alternative access.[26] Recovery plans are improved, resource suppliance is better coordinated, and rescues can be accelerated when drones, 360° cameras, infrared cameras are coupled with VR.[27,28] The collaborative ability of VR enables multiple teams to work on one virtual environment at the same time, contributing expertise from different fields and perspectives.[5,12] Also, in virtual environments, damaged buildings and critical infrastructure can be recreated in an inexpensive way to reconstruct and display possible ways to recovery.[5,11,12]

Barriers

Data Security

In order to accurately visualize the virtual world, data needs to be tracked and integrated directly during the VR simulation. This data can be information, such as city maps, but also more sensitive data, such as biometric data, the user's interaction movements with the device and personal information.[10,15,20,29] Therefore, it needs to be known if and how this data will be saved, sold and what will it be used for by companies providing VR experiences.[15] To get to the forefront of this issue, decision- and policymakers will have to decide early on what protections should be in place for personified data, especially in an emerging technology like VR. [10,14,15,30]

Price

Even though the development costs of VR applications, its software, and the devices have dropped, the price remains a significant barrier. Multiple experts have indicated that the price of the development and production of virtual environments are currently still too expensive to be widely used.[11,12,14,18,19] Especially for public research institutions, the technology is not readily accessible, and the price is perceived as a significant barrier to its use in. However, if compared with the costs of recovery of natural disasters, these investments in NDM are extremely important, since they are only a fraction of the necessary money for recovery in unprepared areas.[11,18,22]

Availability

Within availability, two problems arise when looking at VR and NDM: the necessary internet connection and available data bases necessary for software development.[12] Internet connection is crucial for the use of VR, especially when utilizing it in real-time during natural disasters. Moreover, low bandwidth potentially limits the applicability during natural disasters as well, since reliable real-time information cannot be guaranteed if bandwidth is not large enough.[10,20,30] Moreover, the creation of virtual simulations of natural disasters requires large quantities of datasets in order to run smoothly, hence the availability of data bases for software development hinders its usage.

User experience

Cyber sickness is one of the often-mentioned limitation in the usage of VR, which is assured to improve in the future as the technology develops.[10,11,13,17–19] However, nowadays, it is advised to not keep the headset on for more than 30 minutes.[13] VR is still a simulation in which it is impossible to experience all the senses of the real world. Fire hazards, for instance, can be simulated, but smoke, wind and the sense of smell are not possible to simulate as of yet.[11,17,22] Related to the user experience, is the currently existing male-bias related to the hardware of VR. Here, the head-mounted devices and controllers are not tailored to women as they are not comfortable for female heads, hair and hands.[10,12,13]

From Present to Virtual Reality Futures

The following scenario analysis presents four future developments of VR in NDM. All of them are exploratory scenarios, equally likely to be chosen and policymakers are still influential in which scenario becomes reality.[31]

The main driving forces are software application and software availability. Software application is framed in between tailored and standardized, signifying for which kind of customer, disaster and location VR software has been developed. Software availability is framed as open-source or closed-source, which entails if the source-codes, design documents, and content are made freely available or are distributed under licensed agreement, respectively. The subsequently designed scenarios are: Niche Realities, Virtual Selection, Structured Innovations and VR in this together.

Niche Realities: This scenario is characterized by steady innovation of VR in NDM, stimulated by high investments from the private sector. As the technology is closed-sourced, specialized VR companies, corporate tech giants and NDM corporates are the main distributers of VR. Consequently, VR products are high quality, are well integrated and prove to be highly profitable. The quality is substantial as it is tailored to each given situation, natural disaster, user, and context. Therefore, the effectiveness of VR for the specific disasters is particularly high. Local governments have high interest in VR's use in NDM since decision-making is mostly left to them and virtual environments can be completely tailored to their needs. This increases cost, but quality and effectiveness are prioritized. However, due to the focus of the private sector on profitability, transparency on data collection is only considered when it is in their interest. The price of VR can result in a digital divide as not all actors can purchase it. However, poorer realities are not left out, as they can count on disaster relief organisations, that together with local governments, are the main purchasers of VR for NDM. In this future, NDM is mainly focussed on response, where its highly effective through the context-specific solutions, and preparedness, where efficiency is guaranteed due to the creation of exact environments where first responders and citizens can train in their local surroundings.

Virtual Selection: In this scenario, VR software is tailored to specific locations, disasters and situations, incorporating the needs of the local community, who easily utilize the technology as the threshold is low. The quality is increased, however, the development is time consuming and not streamlined due to VR being open-sourced. Nevertheless, because VR software can be freely transformed and modified, development is broadened, and experimentation opportunities are brought to the table. However, since many can access the software and government have not pushed for data regulation, data transparency is not guaranteed. Also, the private sector is not interested in investing in VR for NMD as its software is fragmented and accessible for everyone, so less profitable. Nonetheless, the private sector collaborates with other stakeholders as the production of VR hardware is still profitable and demanded by the market. To stimulate its usage in NDM, governments provide incentives, such as subsidies, grants and promotional programs, to level the lack of private investors. Furthermore, decision-making on where, when and how to use VR in NDM is done by local governments, although they mainly use it for preparedness and recovery. For instance, in this scenario civilians can be immersed into their own local environments during virtual natural disaster training and local engineers can investigate specific infrastructural improvements for their town.

Structured Innovations: This scenario is characterized by applications of VR in NDM that are standardized, which facilitate broad public use. High standardization lowers development costs, since specific conditions do not need to be met and one software is consistently applied. This appliance is supported by the low threshold for using VR in NDM and facilitated through international collaboration and decision-making. For instance, VR is used widely in training for natural disasters, however, without local conditions. Overall, preparedness is improved because everyone is trained in frequently occurring situations in natural disasters. Moreover, cooperation between world-wide experts is made possible because of international coordination in NDM and open-source VR software, which is proven crucial during disaster recovery. However, even though VR is open-sourced, the hardware and software are licensed out by private companies and overseen by a certification body, which creates some general standards for VR. The certification body is established by the government and helps to reduce the amount of fragmentation, which decreases possibilities of experimentation, limiting technological innovation. In this scenario, governments are the major investors and encouragers for VR in NDM, as the private sector concentrates on development and distribution of the technology in other sectors. Therefore, the government offers funds and grants to level this private disinterest in NDM. Finally, data collection is transparent as the government, due to public concerns, has cautiously put in place regulations on the collection and use of personal data, but privacy issues are not completely overcome, the technology stays open-source.

VR in this together: The scenario is characterized by public and private partnerships as the government recognizes VRs potential in NDM. The private sector has most ownerships rights and therefore, collaboration between the government and this sector is essential to standardize the technology for the greater public. Due to this collaboration, the quality of the product is high enough to be utilized generally and the threshold to use VR is low. International organizations and governments buy into the technology to apply it in programs and international efforts on NDM. Additionally, VR is especially applicable in disaster education, reaching as many communities, regions, and countries as possible. This signifies an extensive use of VR in preparedness, as it is commonly accepted that, in order to raise awareness and train citizens, the recreation of a specific and localized environment is not necessary. Rather, most participants are trained with VR on the most-common risks and strategies within NDM, achieving a cost-effective way to standardization. However, this also brings with it a loss of context-specific answers to NDM, which affects VR usage in real-time response and recovery, because here details, such as local infrastructure, are essential to use the technology effectively. Furthermore, to gain public trust and address data security concerns, governments facilitate legislative regulations on the transparency of data collection and use. Altogether, these factors contribute to its wide-spread use and global applicability.

Key recommendations

- In order to avoid the exploitation of sensitive data, governments should consider adopting stronger legislative frameworks on transparency of data gathering and usage.
- To facilitate the wide-spread and effective usage of VR in NDM:
  - Stand-alone VR devices, where software and applications are installed in advance are independent from an internet connection and need to be developed and promoted.
  - Mobile local networks need to be considered and created to aid and guarantee VR usage during natural disasters.
  - Governments should consider investing into VR hardware and software for usage in governmental programs in NDM.
- Regarding need-driven and context-specific innovation, the United Nations and government sectors should consider stimulating public-private partnerships.

To promote research and development into the use of VR in NDM, open-source VR software will have to be considered by governmental institutes to create equal access to these innovate resources.

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The Adoption of New Digital Technologies in Micro and Small Enterprises in South Africa

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Abstract

Advanced digital technologies are set to change the way we work and live. Policy makers at the national and international levels argue that harnessing these new technologies holds out promise for developing nations to increase their industrial productivity and growth rates, while simultaneously assuring more sustainable patterns of production and consumption. While much has been written about the promises and future risks of 4IR technologies, there is surprisingly little empirical evidence on their adoption and impact at the firm level, either qualitative or quantitative. This is especially the case for developing countries and notably for micro and small enterprises even though they constitute the majority of firms in developing countries. In this contribution we present the results of a unique survey carried out by researchers at the University of Johannesburg measuring the adoption of digital technologies in micro and small enterprises. The results show that micro and small enterprises do adopt new digital technologies and that their adoption can have a positive impact on their capacity to develop and implement new products, services and processes. The survey also explored the importance of key constraints on the development micro and small enterprises including those linked to finance and training and skills needs.

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Introduction

New and disruptive technologies, including advanced robotics and 3D printing, machine learning, big data analytics, cloud computing, the Internet of things (IoT) and smart sensors, are set to change the way we work and live. Summed up under the notion of the Fourth Industrial Revolution (4IR), these technological changes are characterized by the integration of new automation technologies with big data analytics and increased interconnectivity through the Internet as a basis for flexible and intelligent manufacturing that can improve enterprise efficiency and competitiveness. The 4IR extends beyond the factory gates to include the transformation of value chain relations with increased interconnectivity across geographically dispersed stages of the value chain potentially providing the basis for satisfying consumer needs in a rapid and flexible manner. The 4IR will also have a major impact on the economy by transforming business services involving new uses of data depending on internet interconnectivity and the delivery of new services, including financial, energy and supply-chain services, through digital platforms.

Policy makers at the national and international levels argue that harnessing these new technologies holds out promise for developing nations to increase their industrial productivity and growth rates, while simultaneously assuring more sustainable patterns of production and consumption (UNCTAD, 2018, World Bank 2019). This is linked to the understanding that technological change is now occurring at a more rapid pace than ever before, and that the solutions these new frontier technologies offer are better, cheaper and more scalable than what has been available in the past (UNCTAD, 2021).

While much has been written about the promises and future risks of 4IR technologies, there is surprisingly little empirical evidence on their adoption and impact at the firm level, either qualitative or quantitative.[1] This is especially the case for developing countries and notably for micro and small enterprises (MSE) even though MSEs constitute the majority of firms in developing countries. Micro and small enterprises play an essential role in the economy. They provide much-needed job opportunities for burgeoning youth populations; they are a recognized source of new ideas in the implementation of new product and services; and they provide essential inputs services for larger exporting firms. Successful small businesses can grow and acquire a larger stake in the economy.

In order to contribute to filling the big gap in our knowledge about new technology adoption and its

[1] For an overview of the literature, see Lorenz, Kraemer-Mbula and Tregenna (2019).

impacts on micro and small businesses, researchers at the University of Johannesburg carried out a unique survey in the Johannesburg region focusing on manufacturing sector MSEs including non-registered businesses.[1] A wide definition of 4IR technologies was adopted in recognition that MSEs typically lack the scale of production and financial resources needed for adopting more capital-intensive technologies such as interconnected robotic systems linked to centralized data management systems. This wide definition includes the adoption or use of digital tools and services associated with what is often referred to as the 'digital transformation' currently taking hold in the developing world.[2] This includes a firm's relatively passive engagement with technologies accessed through the Internet on digital platforms. Examples include the use of mobile money for making payments, the use of social media as a tool for knowledge exchange, marketing and access to information, and accessing digital platforms for the on-line marketing of goods and services.

Key results from the survey show that MSEs do adopt new digital technologies and services and that these can have a positive impact on their capacity to develop new products, services and processes. The survey also explored the key constraints on MSE development including those linked to finance, and skills needs. Below we present a summary of the basic finding regarding new technology adoption and we draw out the main policy implications. We present the results of a regression analysis showing the relation between the adoption of selective new digital technologies and the firm's innovation performance.

Descriptive statistics: MSE population, technology adoption and innovation performance

Table 1 gives the distribution of the sample population by size in terms of employment. Of the 677 firms surveyed slightly less than 67 percent were micro with 5 employees or less, and just over 33% were small sized with between 6 and 25. About 33 percent of the total sample of businesses are registered with the South African Revenue Service (SARS). The share of firms registered increases with size, passing from 17% for micro enterprises to 41% for small sized enterprises.

Table 1. Distribution of firms by employment

Size category	Micro ≤ 5 employees	Small 6 – 25 employees	Total
	66.9%	33.1%	100.0%
N	*453*	*224*	*677*

Data source: Innovation in Micro and Small Enterprises in Johannesburg Survey, University of Johannesburg, 2019.

Table 2 shows the adoption rates of 4 technologies that play a key role in the ability of MSMEs to participate in the digital economy. These include having a business website, engaging in e-commerce, using social media and using mobile banking. The costs of setting up a business website have dramatically declined with the availability cheap web design packages and of the four digital technologies considered having a website is the second most frequently used, concerning 23.8% of the sample of firms. There are large differences in adoption rates across firm size categories with 9.5% of micro firms having a website compared to 43.7% for small sized firms respectively. This may reflect that micro enterprises' lack the necessary skills or knowledge for setting up a website or it may simply reflect a perception that there is little to be gained in so far as their markets are limited to a local neighborhood. On-line commerce has expanded since it has become relatively easy to set up an online store. Small businesses only need an internet connection to run various e-commerce solutions and a shipping process. As in the case of having a business website, adoption rates are very low for micro businesses at 6% compared to about 22 for small sized enterprises.

Social media has multiple uses. It can be used as a marketing tool for sales promotion and to provide customer service and support. It can also be used as a tool for knowledge exchange and for employee learning. Blogs, social networks and forums can be means for exchanging ideas and for acquiring ideas about new technologies and products[3]. Using social media only requires a smart phone and an internet connection. On average at 32.4% it is the most used of the 4 digital technologies examined. Further, the differences in adoption rates between micro and small sized business are less pronounced compared to those for having a website or using e-commerce which reflects the low

[1] This survey was conducted under the project "Community of Practice in Innovation and Inclusive Industrialisation" hosted by the South African Research Chair in Industrial Development, at the College of Business and Economics, University of Johannesburg.
[2] See the country diagnostic reports from the World Bank's Digital Economy for Africa Initiative. https://www.worldbank.org/en/topic/digitaldevelopment/brief/digital-economy-country-diagnostics-for-africa
[3] See Bhimani et al. (2019) for a survey of the literature on social media and innovation.

cost and accessibility of social media in terms of skills requirements.

Table 2. Shares of firms adopting new digital technologies

	Micro (≤ 5 employees)	Small (6-25 employees)	Total
Business website	9.5%	43.7%	20.8%
E-commerce	6.0%	22.3%	11.4%
Social media	27.2%	42.8%	32.4%
Mobile banking	5.5%	15.2%	8.7%
N	*453*	*224*	*677*

Data source: Innovation in Micro and Small Enterprises in Johannesburg Survey, University of Johannesburg, 2019.

The rate of adoption of mobile banking is quite low especially when compared to the wide use of on-line mobile money services by small businesses in such East African countries as Kenya or Uganda.[1] The low adoption rates among micro and small businesses can be explained in part by the fact that mobile banking in South African is a service mainly offered by the banks and requires a bank account which micro enterprises and small firms often lack. There is very limited diffusion in South Africa of mobile money or mobile wallet for which a bank account is not required and where value is stored virtually (e-money) in an account associated with a SIM card.

Table 3 shows that MSME do innovate new products, services or processes and that while the rates of innovation for micro firms are lower than for small-sized enterprises, the difference is less pronounced than for the adoption of such digital technologies as having a website or engaging in e-commerce. While the rates of innovation may appear high, it needs to be appreciated that the figures are for innovations that are new to the firm but not necessarily new to market and much of the innovative activity measured will be the result of the diffusion of new products, services and processes that haven been developed elsewhere.

Table 3: New products, services or processes introduced in 2019.

	Micro (≤ 5 employees)	Small (6-25 employees)	Total
New to the firm innovations introduced during 2019	28.5%	46.0%	33.1%
N	*453*	*224*	677

Dara source: Innovation in Micro and Small Enterprises in Johannesburg Survey, University of Johannesburg, 2019

Table 4 presents the results of the regression analysis showing whether the use of the 4 digital technologies has a positive impact on the likelihood of innovation. The strongest positive result is for the use of social media which shows the potential of this technology to be used for knowledge sharing and for acquiring ideas for new products, services or processes. The results also show that the use of mobile banking, although not widely adopted, has a positive impact on innovation. A possible explanation is the savings of time and transactions costs that mobile banking results in, thus freeing up resources for other uses including investments in innovation (Bångens and Söderberg, 2011).

Table 4: Probit regression: Impact of new digital technologies on innovation

VARIABLES	*New to Firm products, services or processes*
Business website	-.23
Social media	.44***
E-commerce	.18
Mobile banking	.40**
Size	
Micro	reference
Small	.40***
Constant	-.71**
N	

*** significant at .01 level; ** significant at .05 level
The regression controls for sector of activity

Conclusions and recommendations

Micro and small enterprises do innovate new products, services and processes and the evidence from the University of Johannesburg survey shows that the adoption of social media and mobile banking can have a positive impact on their innovation performance. Adoption rates are low with less than half of the businesses using these technologies and the rates are

[1] World Bank Enterprise survey data for 2013 shows that about 49% of firms in Kenya and 43% in Uganda used mobile money at this time and that the adoption rates were higher for small than for medium-sized or large firms. See Lorenz and Pommet (2020).

especially low for micro enterprises. This points to the need for polices to support the adoption of digital technologies in these firms. Micro firms in particular face important constraints in finance and skills development. Over 45% of the micro businesses state that they are credit constrained and could benefit from more inclusive access to mobile banking services. Over 64%% of the micro businesses state that have difficulties finding employees with the required skills and there is limited access to the external training needed for more technical and business management skills. Less than 3% of the entire population of businesses state that they have benefited in any way from government subsidies or incentives and a similarly small share state that they have received support from a formal institution such as a government agency, a university, NGOs, or incubators. The results from the survey indicate that there is an unrealised potential for micro and small enterprise to benefit the economy through their capacity to develop new products, services and implement new processes. Government policies could usefully support the creation of technology platforms promoting the development and adoption of digital technologies. Start-ups and technology adoption in young firms could be supported through policies to finance incubators, accelerators and seed investment funds. Finally small and micro business can succeed in knowledge intensive sectors such as ICTs and pharmaceuticals and for these firms there is a need to promote links between micro and small firms and universities and technical transfer institutes. Micro firms have been largely ignored in the policy debate due in part to the lack of available evidence on their activities and performance. We believe that the results of this survey point to the need for more specialized surveys on technology adoption in micro and small firms that largely remain a hidden engine of innovativeness in the economy.

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D. Big Earth Data, satellites and remote sensing

Utilizing advanced sensing technologies for SDGs

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Sensing as a core technology in "STI for SDGs"

All science begins with measurement. By extending our bodily senses, sensing technologies enable us to reveal the laws of nature, quantify the state of society we live in, and act upon them according to our needs. The very existence of the manifold global challenges identified in the UN 2030 Agenda could only be recognized through measurement; countermeasures for them can also be sought only through measurement. In the recent COVID-19 pandemic, rapid, accurate, and reliable PCR tests are crucial for early detection of infection, enabling early treatment and isolation. Around the world we have been reminded of the significance of diagnosis and inspection.

"Digital transformation", a major social challenge for future growth in many countries, requires data obtained by sensing. Japan's digital transformation is driven toward the vision of "Society 5.0", in which data obtained in physical space is processed in cyberspace and then fed back into physical space [1]. Digital transformation is implemented in various fields such as agriculture, healthcare, infrastructure, mobility, meteorology, and ocean studies. In such applications, along with cloud computing, advanced sensing technologies incorporated in the Internet of Things (IoT) play key roles.

For example, data obtained from satellite observations, combined with data from field observations, are being used to solve global challenges such as mitigating/adapting to climate change, managing water, preventing air pollution, and conserving forests. The Group on Earth Observations (GEO) [2] is an international framework that plays a major role in earth observation. DIAS [3], Japan's data infrastructure, integrates and accumulates various types of large-scale data, including satellite observations, and has been used for various purposes, such as high precision drought prediction in Asia and Africa contributing to the water resource management plans in ODA projects.

These are just a few examples of sensing technologies utilized in STI for SDGs. Sensing is one of the core technologies that cut across many of the SDGs (Table 1).

Table 1: Example of applications and technological challenges of sensing technologies for SDGs

Application field (SDG)	Possible applications and challenges of sensing technologies
Agriculture (SDG2)	• applications: Crop growth monitoring using drones, automatic tractors, satellites, etc.; sensing for improving water and fertilizer use efficiency; photosynthesis measurement for quantifying material cycle in the farm field; food taste and smell sensing; food safety and freshness management; Point of Care Test (POCT) • challenges: Prediction of changes in the field environment due to global warming; realizing automation by sensor fusion
Healthcare (SDG3)	• applications: Measurement of health-related data by wearable devices, implantable devices and the devices put in the ambient environment (healthcare IoT) for early prediction, detection and management of diseases, e.g. continuous glucose monitoring (CGM) • challenges: Biochemical measurement by minimally invasive devices with long lifetime; data processing, clinical study to derive medical value from measurement
Water and Sanitation (SDG6)	• applications: Monitoring of global water cycle including rainfall, snowfall, river flow, evapotranspiration, groundwater, etc.; water quality testing; control, diagnosis, and maintenance of water treatment facilities and culvert facilities by integrating sensor technology, ICT, and AI • challenges: Improvement of the accuracy of precipitation observation and flood forecasting; data coverage of groundwater, snow cover, and typhoons

Energy (SDG7)	• applications: Prediction of sunshine duration and air flow for renewable energy; power monitoring for grid stabilization; preventive maintenance of power generation, transmission and distribution systems; environmental impact monitoring; nuclear safety monitoring • challenges: Sophistication of weather forecasting; smart meters for small power customers; equipment degradation measurement
Economy (SDG8), Innovation and Infrastructure (SDG9)	• applications: Analysis and measurement systems for advanced research; automation of production systems; monitoring of aging deterioration of social infrastructure; prediction, detection, and impact assessment of natural disasters • challenges: Developing frontiers of scientific instruments; application of AI; operando measurement; manufacturing process measurement; wide area monitoring
Cities (SDG11)	• applications: Dynamic maps for realization of automated driving; measurement of urban environments; crime and security monitoring; disaster measurement • challenges: Data utilization to mitigate traffic and communication congestion; data processing technology in the era of "trillion sensors"
Consumption and Production (SDG12)	• applications: Monitoring food loss in the supply chain; monitoring resource reuse; natural resource exploration and measurement • challenges: Advanced logistics monitoring (e.g. using blockchain)
Climate Change (SDG13)	• applications: Earth observation; early warning systems for extreme weather conditions such as droughts, floods, etc. • challenges: Sophistication of satellite observation, atmospheric measurement, and oceanic measurement
Ocean Biosphere (SDG14)	• applications: Observation of biodiversity; management of marine ecosystems; measurement of marine plastics • challenges: Sophisticated satellite observation; autonomous undersea sensing
Land Biosphere (SDG15)	• applications: Forest conservation; biodiversity observation; management of forest ecosystems • challenges: Advanced satellite observation; Utilization of drones

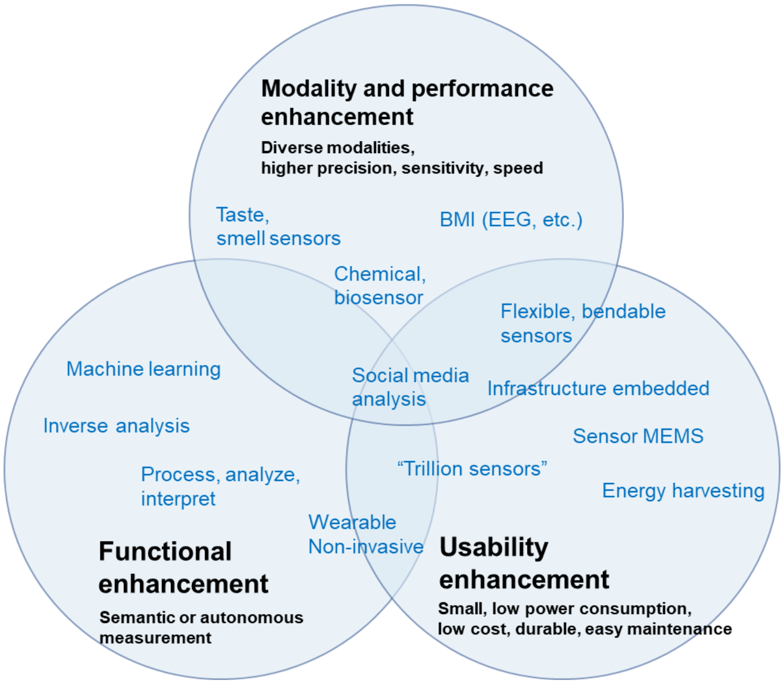
Source: created by the authors based on past reports from the Center for Research and Development Strategy, Japan Science and Technology Agency

Emerging technological frontiers of sensing

Sensing technologies continue to advance in three directions: (1) modality and performance enhancement, (2) usability enhancement, and (3) functional enhancement. Innovative technologies are emerging in all three aspects (Figure 1) [4].

1. *Modality and performance enhancement*: Developing new physical, chemical, biological, and quantum sensors will enable previously impossible measurements. Even in the existing sensing modalities such as electromagnetic waves, measurement in the terahertz band, which has been difficult to generate, control, and detect, has recently become possible. Terahertz imaging is expected to be applied in various situations such as living cell imaging [5] or hazardous gas detection [6]. In addition, achieving higher precision or sensitivity can open completely new applications. For example, a high-speed camera and computer vision at a frame rate of 1000 frames per second (much faster than perceivable by humans) have been realized and are expected to be applied to high-speed inspection, intelligent display, robot manipulation, etc. [7]
2. *Usability enhancement*: Reduced size, lower power consumption, lower cost, durability, and easy maintenance are required for implementing a large number of sensors in society. In healthcare, the wearability of sensors is also important. Among emerging wearable technologies is a device that measures the oxygen concentration in the blood by attaching an elastic film with optical sensors to the skin [8] or an EEG sensor with a flexible amplifier circuit built into a sheet [9].
3. *Functional enhancement*: The measured data are combined, analyzed, and interpreted by the integration of AI technology in the sensing system. Autonomous measurement enabled by mobile robots is another path to achieving higher functionality of sensing.

Figure 1. Three directions of emerging sensing technologies.



Source: Modified and translated from [4].

Today, many sensors are connected to the cloud, forming a Cyber-Physical-System (CPS). Such a CPS requires edge devices, and high-performance cloud servers and networks on which data are gathered, integrated and analyzed by advanced AI and machine learning methods. The three directions of technological advancement, namely, (1) modality diversification and performance enhancement, (2) usability enhancement, and (3) functional enhancement correspond roughly to technological challenges at the sensor-level, sensor-terminal-level, and system-level, respectively [10].

1. At the *sensor* level, the main challenges are to achieve high sensitivity and diverse modalities making use of innovative detection principles, novel materials, quantum technologies, biotechnologies, ICT, etc.
2. A *sensor terminal* refers to a device installed near the measurement target, consisting of sensors, analog-to-digital conversion circuits, batteries, and communication circuits. How to integrate and implement various functional blocks such as sensor control, analog front end, temporary data storage, data conversion, feature extraction, power supply control, energy harvesting, and communication functions in one device (e.g. on a CMOS board) is a challenge at the sensor terminal level.
3. At the *system level*, the challenge is to design the architecture of the sensing system, which consists of edge-side equipment, sensor terminals, and networks. System-level challenges include: sensor fusion, which combines multiple sensing data to extract valuable information; event-driven sensing, i.e. actuating or modifying information transmission to upper/lower layers upon detecting a temporal change in sensed data; active sensing, in which actuators and sensors work together to actively acquire the next data based on the previous data. The reliability and security of sensing systems are also major issues.

If conducted independently, R&D at each level will not lead to a useful sensing system. Coordination of R&D at all three levels according to the overall architecture is necessary. It is also important to promote standardization of technologies in each layer within the framework of the CPS in order to expand the range of applications.

Utilizing advanced sensing in international projects on STI for SDGs

The Council for the Promotion of Science and Technology Diplomacy, established by the Ministry of Foreign Affairs of Japan, has positioned STI as a "bridging force" that contributes to the SDGs and emphasizes the importance of acquisition and analysis of global data [11] . To fully utilize advanced sensing technologies for SDGs, international collaboration is essential. SDGs call for building, boosting, and brokering STI in international partnerships [12].

One such initiative is Japan's SATREPS (Science and Technology Research Partnership for Sustainable Development), which promotes joint research with developing countries funded by a combination of the national STI budget and ODA. SATREPS addresses problems that cannot be solved by a single country (i.e. "global issues") in various fields such as environment, energy, bioresources, disaster prevention, and infectious diseases. Based on the needs of developing countries, the program aims for research outcomes of practical benefit to both local and global society. It also emphasizes human resource development in developing countries [13].

SATREPS has implemented 157 projects in 52 countries between 2008 and 2020. In many projects, sensing technology has played a major role. The following are some of the recent examples.

In a project led by Tsuboi et al. [14], research on traffic flow analysis and management based on traffic big data is conducted in Ahmedabad, India [15]. They are inventing methods for data acquisition and analysis suitable for the unique traffic situations in the city (where roads are congested with small vehicles), combining multiple sensing methods such as the installation of traffic cameras, drones, and onboard cameras. Utilizing such data, they are aiming toward a low-carbon smart city where multimodal transportation is realized.

A project led by Wada et al. [16], aims to build sustainable aquaculture technology in Indonesia. They have developed a sensor node that is self-powered by solar panels, and are working to collect big data on the local marine environment (water temperature, dissolved oxygen concentration, salinity, chlorophyll, etc.) and the production history of marine products. The advancement of aquaculture and fisheries is expected to lead to virtuous economic cycles in fishing villages and sustainable production of marine products [17].

Another project led by Inoue et al. [18] aims to realize a real-time earthquake intensity observation network in the Philippines. They developed and installed networked intensity meters consisting of an inexpensive digital acceleration sensor with sufficient resolution, a seismic intensity display, and a data transmission device [19]. This system contributed to the evacuation of residents during the initial response phase after the eruption of Taal Volcano in 2020.

There are many other examples in which data usage played a key role in problem-solving programs, such as climate change prediction [20], the development of an early warning system for infectious diseases [21] in South Africa, or the construction of a climate change adaptation strategy in Thailand [22]. In such programs, systems for collecting, sharing, analysing, and utilizing data from satellites, oceans, or field observations are providing the means to solve socio-economic problems.

It is crucial that the technologies and experiences developed in the SATREPS project, customized to local needs, can also be adapted for application around the world. In addition, a lesson learned from all SATREPS projects is the importance of fostering a long-term international network of researchers.

Challenges in the utilization of sensing data for SDGs

Emerging sensing technologies can provide powerful innovative solutions to global problems. On the other hand, when handling the data obtained from such technologies there are institutional, social, and ethical issues to be addressed.

Open data and data platform: The importance of "open data," where research data is disclosed and shared, has been highlighted [23]. We must establish rules for ensuring data reliability, access, and reuse. Well-maintained data platforms should be built at the national level for global use.

Security of sensing systems: Allowing sensing systems to be eavesdropped on or hijacked by a cyber-attack causes serious damage to society. Proactive countermeasures to cyber-attacks are necessary.

Ethics in sensing: Data related to healthcare or other personal activities require sensitive handling to protect privacy. Sensing technologies may be diverted to military use contrary to the developer's original intention. Tampering or misuse of measured data can have an enormous impact on society. We must anticipate such issues (ELSI) and maintain integrity in R&D.

In summary, we examined how the development and implementation of advanced sensing technology can play a key role in achieving the SDGs. New sensing technologies will continue to emerge boasting modality diversification and performance enhancement, usability enhancement, and functional enhancement. We propose the following actions for their better utilization:

1. Promote interdisciplinary research to create innovative sensing technologies in ways that integrate R&D at all layers including system level, terminal level, and sensor level.
2. Clarify rules for open use of data and establish data platforms at the national level.
3. Expand international partnerships in the utilization of sensing technology as solutions to local and global problems.
4. Raise awareness concerning data ethics associated with advanced measurement and improve cyber-security literacy concerning sensing systems.

Acknowledgement

This report is partly based on previous reports ([4], [10]) by the Center for Research and Development Strategy, Japan Science and Technology Agency (JST-CRDS). Aya Araoka (main author of [10]), Ryoji Nakamura, Yuya Miyazono at JST-CRDS have provided inputs on frontiers and applications of

emerging sensing technologies. Yuji Kato and Tomo Murata at the Department of International Affairs, JST provided comments on the relevant cases in SATREPS.

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Big Earth Data for Sustainable Development Goals

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Introduction

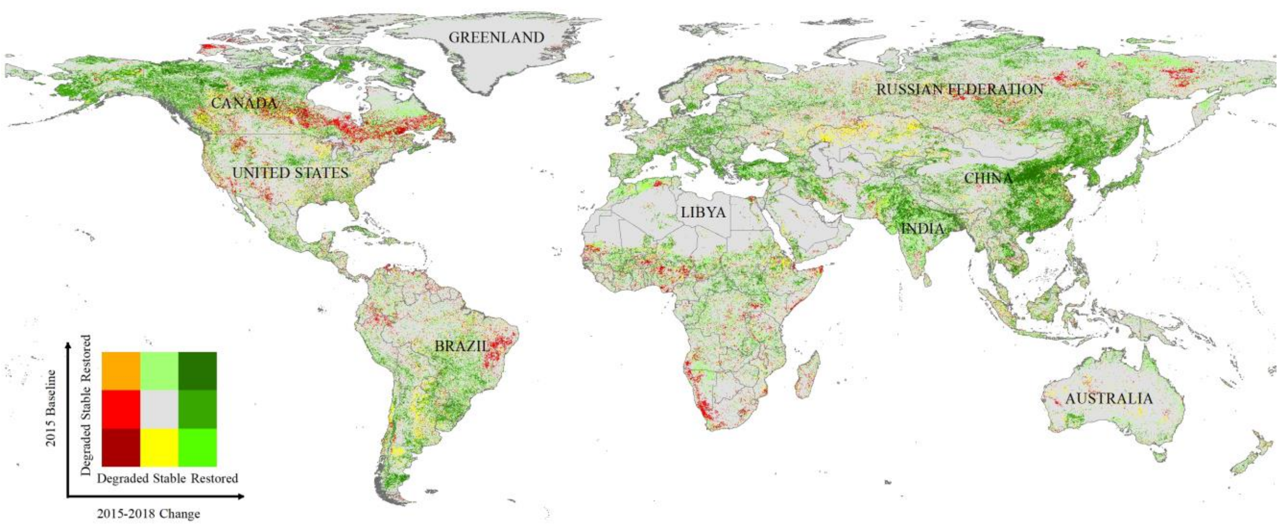
The pace of technological development is expected to continue rising exponentially (Ohmae 2004), with an unprecedented pace of progress in digital technologies[88], providing new opportunities for technological solutions to Sustainable Development Goals (SDGs) (United Nations 2015). Increasing collaboration in response to the global COVID-19 pandemic has brought a chance to diversify our efforts and enhance opportunities for countries to improve the extent to which scientific evidence and innovative technological solutions can be adopted. Frontier technologies such as artificial intelligence, cloud computing, and big data all have enabled synthesis of reliable information (Guo et al. 2014). The improved frequency and accuracy of data collection must play a key role in implementing SDGs (Guo et al. 2021).

As witnessed during the pandemic, digital technologies facilitated actions in line with SDGs in different countries, but sustained efforts are needed for a science-technology-policy framework. Decision makers need adequate scientific support to interpret and develop correct strategies, and precisely evaluate progress, limitations, and deficiencies. Unfortunately, only 56% of the 230+ SDG indicators have established methods and assessment data globally, while only 42% have established methods but no data, and 2% lack any method or data[89]. Therefore, knowledge and data gaps restrict science-driven policy and decision support systems (Guo 2019), mainly because of regional differences in abilities, especially in developing countries (Guo 2018).

The Value of Data: Towards Big Earth Data

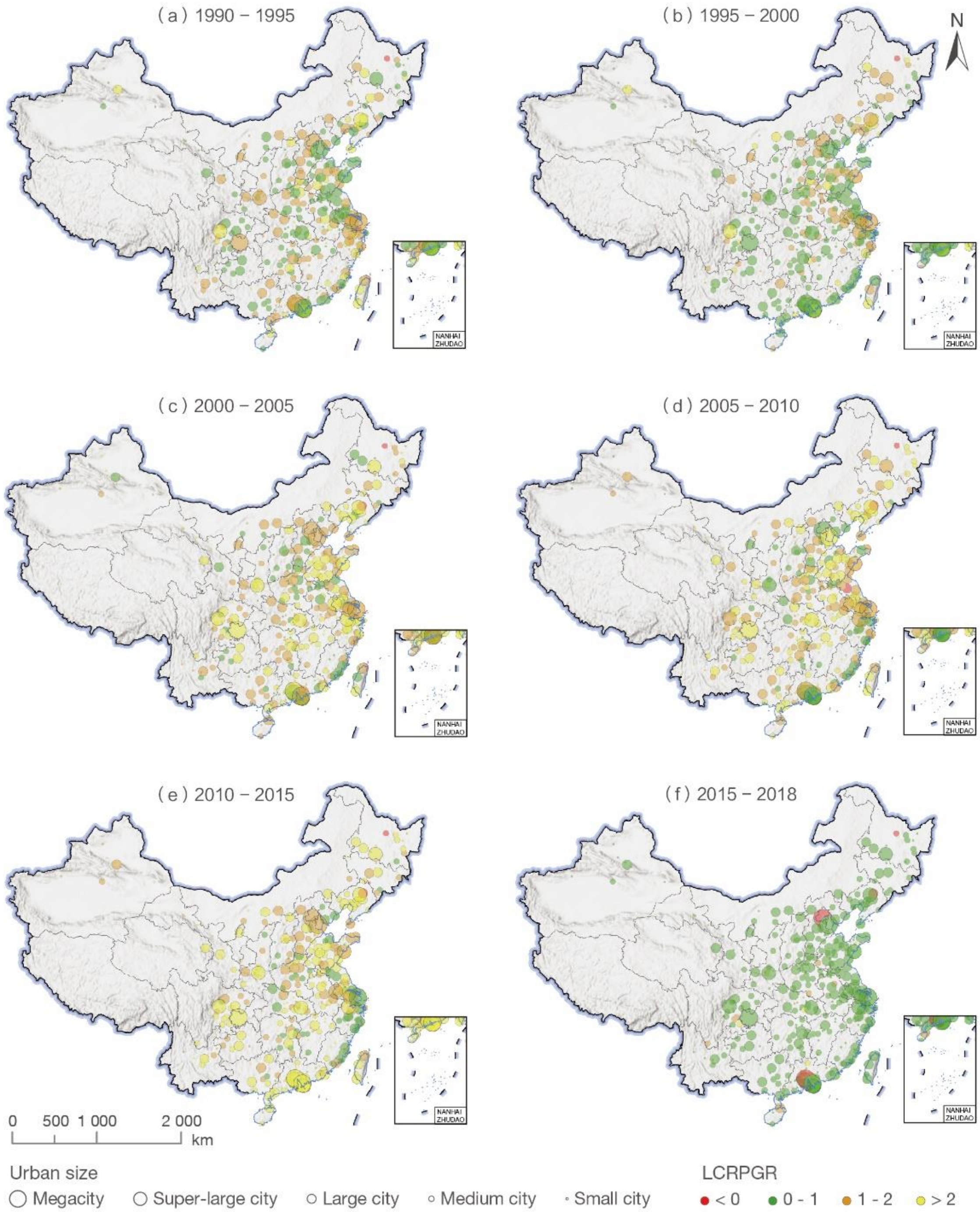
Lack of data is limiting progress towards SDGs. For example, in the Asia Pacific region, more than half of the SDG targets lack data needed to measure progress on SDGs in the region (United Nations Economic and Social Commission for Asia and the Pacific 2020). Meanwhile, data quality is increasingly critical for big data due to diversifying sources and formats (Côrte-Real, Ruivo, and Oliveira 2020). The concept of "Big Earth Data" has thus emerged to integrate the vast amounts of big data generated by modern digital infrastructures and Earth observation. The discipline of Big Earth Data science is a new approach to evidence-based decision making towards the benefit of society and the environment, while ensuring economic development (Guo et al. 2020).

Fig. 1. Spatial distribution and dynamics of global land degradation benchmarks from 2015 to 2018



[88] https://www.un.org/sites/un2.un.org/files/un75_new_technologies.pdf
[89] https://unstats.un.org/sdgs/files/Tier%20Classification%20of%20SDG%20Indicators_28%20Dec%202020_web.pdf

Fig. 2. Changes in the ratio of land consumption rate to population growth rate (LCRPGR) of 433 cities in China from 1990 to 2018 (Guo 2019)



Big Earth Data consists of all data related to Earth's interior, land and ocean surface, atmosphere, and near-space environment. It is the basis of data-intensive scientific discovery in the Earth sciences (Guo 2017). Big Earth Data provides a comprehensible and intuitive integration of multi-source data. For example, multiple big data sources were used to evaluate global land degradation from 2015 to 2018, finding China's net restored land area increased 60.30%, accounting for a fifth of the world's total, making it the number one contributor to global land degradation neutrality (Figure 1). Big Earth Data analytics were also used to assess the scale of urbanization from 1990 to 2018 in China, integrating data for urban land-use efficiency, gross domestic product (GDP), population, and global 10 m impervious surface satellite products (Figure 2).

The Big Earth Data approach can thus help to generate information on complex management, productivity, and developmental problems and support policy and decision-making for issues such as global climate change and international initiatives such as the UN SDGs. There have been several implementations of this concept by the "Big Earth Data Science Engineering Program" (CASEarth) of the Chinese Academy of Sciences (CAS). The focus of these efforts is to 1) fill in missing data and generate new innovative sources of data to diversify Big Earth Data for SDGs, 2) develop methodologies and data analysis techniques to evaluate SDGs utilizing Big Earth Data, and 3) provide decision support to SDGs by monitoring and identifying progress. CASEarth is planning to translate Big Earth Data into SDG-related information at global, regional, national, and local scales to facilitate policy and decision development processes nationally and globally (Guo 2019). CASEarth prioritizes Zero Hunger, Clean Water and Sanitation, Sustainable Cities and Communities, Climate Action, Life below Water, and Life on Land (SDGs 2, 6, 11, 13, 14, and 15). CASEarth has successfully demonstrated the applications of Big Earth Data in sustainable development (Guo et al. 2021) through a series of reports detailing more than 100 case studies submitted by China to the UN General Assembly sessions in 2019[90] and 2020[91]. CASEarth is also featured on the UN's 2030 Connect platform as one of the current 24 partners.

Big Earth Data Policy Considerations to Leave No One Behind

Big Earth Data should be seen as a Technology Facilitation Mechanism (TFM) that requires the generation and flow of complex multi-source data. Integrating the Big Earth Data approach within the science-technology-policy framework requires several important considerations to facilitate progress towards the SDGs.

Data Policy – Improving Data Quality and Data Standards at Scale

Two of the fundamental barriers to implementing Big Earth Data are the lack of high-quality data and access to data. Both result in a loss of valuable information for effective implementation of more advanced data analysis and information discovery methods. Therefore, both quality and interconnectivity of datasets are necessary at multiple scales. At national and local scales, systems for collecting, storing, and integrating data must be established or improved. Investment in data infrastructure should therefore be prioritized as a TFM to improve preparedness and response in case of biological and other disasters and for SDGs.

At regional and global scales, there is a need to initiate and sustain meaningful multi-stakeholder cooperation towards developing common data platforms for data sharing and analysis, which will facilitate unified standards, formats, and units or standard conversion algorithms, improving data interoperability. This will help to set up global long-term mechanisms to fund and facilitate international scientific cooperation on systemic and trans-boundary risks and crisis response.

As witnessed during the initial month of the COVID-19 pandemic, timely sharing of scientific data is critical, and immediate sharing of gene sequence data of the coronavirus led to the immediate mobilization of the scientific community the world over towards ongoing research and vaccine development efforts and has resulted in the encouraging progress made thus far.

Data Infrastructure

The complexity, volume, and dimensionality of data are inherent in Big Earth Data, and therefore require computing capacity and infrastructure investments that are not reproducible everywhere. However, cloud computing infrastructure and digital connectivity enable access to these computing resources from thousands of miles away. Therefore, in tandem with improving data collection, connectivity, and interoperability, a cloud-based big data platform for SDGs is needed to allow rapid data analysis. Such platforms will empower science-technology-policy frameworks, especially at lower governance levels such as municipalities and provinces, and for developing countries that lack the resources to develop domestic systems linking indigenous knowledge. For example, CASEarth's Big Earth Data cloud platform provides an agricultural sampling system utilizing smart phones to

[90] https://www.fmprc.gov.cn/mfa_eng/topics_665678/2030kcxfzyc/P020190924800116340503.pdf
[91] https://www.fmprc.gov.cn/mfa_eng/topics_665678/2030kcxfzyc/P020200927650108183958.pdf

provide a cost-effective data solution for monitoring and tracking crop planting status at any time and in any place. More than 100,000 surveys of crop planting structures are obtained by users every year. The potential of such systems is enhanced through active data sharing. Therefore, countries having more scientific and technological capacity must shoulder more responsibility in both developing cloud infrastructure and promoting the culture of sharing and encourage collective ownership for SDG-related scientific data, methods, and achievements.

Such Big Earth Data systems for SDGs also hold immense opportunities for information outreach to enhance public participation and support, which is critical for the realization of SDGs. The public has limited access to relevant and important information on SDGs and the impacts on their lives, but these cloud-based platforms, designed with user friendly interfaces and simplified information, provide the opportunity for scientists and media to cooperate in broadcasting research to create public awareness.

CASEarth is preparing the SDG-1 satellite for launch on 24 September 2021. It will provide necessary information about national urban growth, monitor the quality of coastal and offshore environments, and give insights into the status, patterns, and regional gaps in socioeconomic development in China at a very fine scale. The acquired Earth observation data will be released to the world, which will contribute to SDGs.

International platforms for scientific cooperation

Big Earth Data also requires strong multi-stakeholder cooperation towards a comprehensive strategy, since integration of multi-source data requires timely and effective communication between scientists and government, enterprises, and individuals. This can be facilitated through scientific institutes such as the International Research Center of Big Data for Sustainable Development Goals announced in 2020 by Chinese President Xi Jinping during his address at the 75th United Nations General Assembly General Debate session. The center focuses on 1) data and information; 2) education and training; 3) infrastructure development; and 4) free transfer of technology.

Conclusion

The year 2020 began the “Decade of Action” for achieving the Goals of the UN’s 2030 Agenda for Sustainable Development. The relevance of the 2030 Agenda and SDGs has become more evident in present times. In particular, the effort towards the environmental dimension of the SDGs requires committed and sustained efforts to ensure improvements. For the SDGs to be successful, traditional barriers between institutions, countries and sectors that block the sharing of data, information, and knowledge must be removed. To ensure no one is left behind, there is a need to capitalize on improvements in tools, analytical methodologies, and techniques to collect, organize, and utilize various sources and large quantities of data for informed, science-driven policy all over the world. The concept of Big Earth Data envisages integration of this multi-source data and information and provides potential for a new norm of sharing towards sustainable development. Big Earth Data can empower digital technologies that, as witnessed during the pandemic, have provided opportunities at regional and global levels.

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Mega-constellations: Benefits and implications of the new era in spaceflight

UN Office for Outer Space Affairs

Abstract

Mega-constellations, a new rapidly emerging technology, could amplify existing space benefits and tap new markets, especially in Earth observation and broadband. However, the concept also represents challenges to the safety, security, and sustainability of the space environment. This paper analyses the drivers behind mega-constellations and explore their impacts. It also provides recommendations by the United Nations Office for Outer Space Affairs to mitigate the negative ramifications.

Introduction

Space activities are a game-changer, empowering humanity and contributing significantly to sustainable socioeconomic development (see Figure 1). Satellites also power the economy underpinning at least 10 percent of the Gross Domestic Product (GDP) in advanced economies[92]. Recently, the satellite industry is booming, diversifying the sector and unlocking novel opportunities. Stemming from these advancements, a new concept – mega-constellations – was born. Mega-constellations offer great prospects for the space industry and across different industries, including communication, weather monitoring, disaster management and climate action[93]. However, they also carry risks exerting pressures on the safety, security and sustainability of the space environment. Attention must be devoted to these impacts to find agreeable, mutually beneficial and multilateral solutions.

This policy paper aims to address the following questions:

What transformative benefits mega-constellations offer to attract attention and investments for their realization?

What are the negative implications mega-constellations carry across different domains and what are some of the policy solutions to address these issues?

Figure 1: The contribution of Copernicus and EGNSS to Sustainable Development Goals according to the relevance of their impact. Around 40 percent of the 169 SDG targets benefit from geolocation and Earth observation. (Credit: United Nations)

Mega-constellations: The promise of a better future

Digital Divide

The current gap in Internet access remains strikingly high. Global Internet user penetration is at almost 54 percent and only 19.1 percent in the Least Developed Countries[94]. Mega-constellations aspire to tap into unserved and underserved areas[95], creating a significant market of affordable global internet access[96]. Past efforts were devised with satellites in higher orbits impacting costs as well as connection speeds virtually impeding the demand-driven approach[97]. The current downstream digital revolution could finally achieve this

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long-standing ambition. Bridging the digital divide through mega-constellations would help achieve the recommendation 1A of the Secretary General's High-Level Panel on Digital Cooperation[98] and the SDG 9.C Target[99].

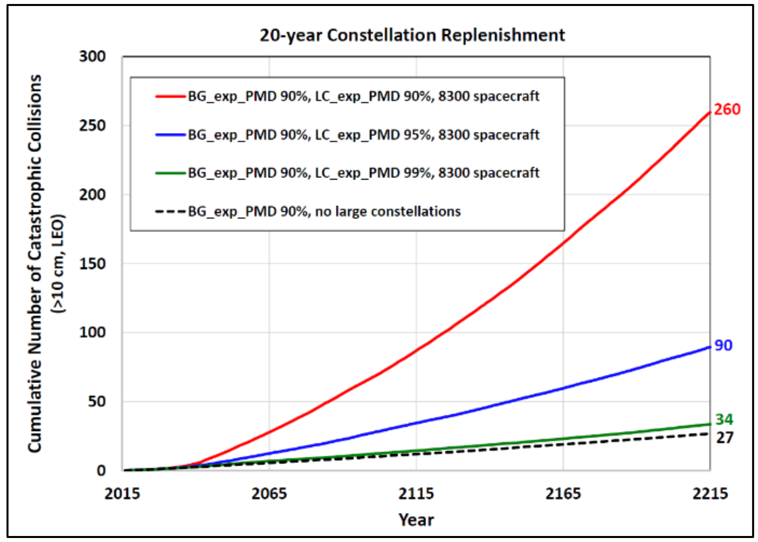
Earth Observation

The large-scale Earth Observation (EO) constellations in LEO can significantly improve our sensing capabilities by complementing gaps in high-precision data collected by bigger satellites in different orbits. They will enable access to near real-time imagery and data available to end-users across the globe immediately unlocking new capabilities, opportunities and markets[100]. These unique insights can, among other countless benefits, improve our understanding of the health of the planet, further enhance policy and decision making, help more efficiently combat crime at all levels of society and contribute to bridging the space capabilities gap.

Mega-constellations: Not a trouble-free innovation

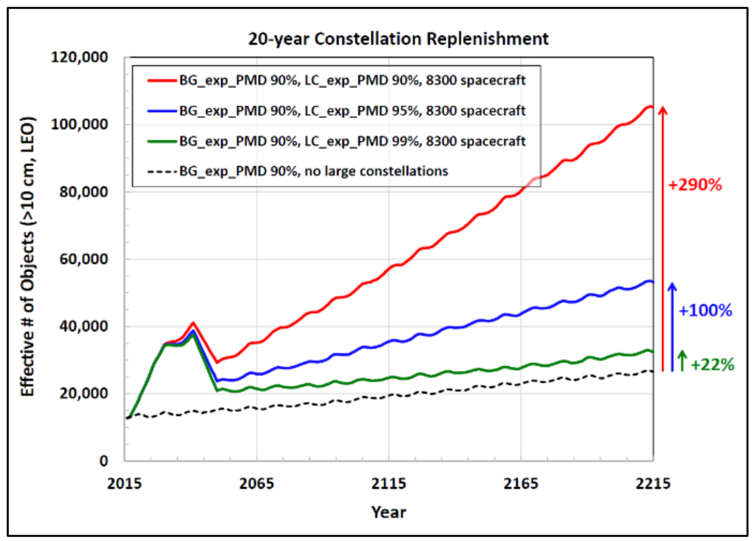
Since 1957, over 10,600 thousand payloads have been launched to space with 1,264 in 2020 alone[101]. The planned mega-constellations could increase this number severalfold and, if unregulated, they could exacerbate the existing sustainability challenges. Research shows they could significantly increase orbital density and collision rates in the future[102] especially in LEO regions through which spacecrafts must fly to get to higher orbits and beyond. Maintaining orbital density within reasonable limits requires action on behalf of stakeholders. Without an immediate and substantive response to these new realities, the space industry, and indeed the modern society, could face serious problems. The space debris population will grow rapidly (see Figure 3) and the probabilities of collisions increase considerably (see Figure 4)[103]. Higher conjunction risks translate into additional costs, requiring financial, human and technological capital for reinforced monitoring and communication while also reducing mission length of spacecrafts in case of avoidance maneuvers. Eventual collisions could prove catastrophic for the industry and the modern society in the worst-case scenario of a chain reaction.

Figure 3. Cumulative number of Objects in LEO >10cm



Credit: NASA ODPO

Figure 4. Cumulative number of Catastrophic in LEO Collisions



Credit: NASA ODPO

Mega-constellations also pose problems for ground-based astronomical observations. The International Astronomical Union communicates two scientific concerns[104] regarding their impact. Firstly, the brightness of LEO satellites can be detrimental to ground-based astronomical observations adding another layer of complexity to mitigate the negative impacts of the growing satellite population.

98 UN Secretary-General's High-level Panel on Digital Cooperation (2019) *The Age of Digital Interdependence*, p. 4.
99 Resolution of the United Nations General Assembly adopted at seventieth session (2015) UN General Assembly Document, A/RES/70/1.
100 DNV GL (2020) *Technology Outlook 2030*, p.54-55.
101 UNOOSA Online Index of Objects Launched into Outer Space. As of 31 March 2021. https://www.unoosa.org/oosa/en/spaceobjectregister/index.html
102 Somma, Lewis, Colombo (2017) *Sensitivity Analysis for a Space Debris Environment Model*.
103 Liou et al. (2018) *NASA ODPO's Large Constellation Study in* NASA Orbital Debris Quarterly News, vol. 22/ 3, p. 4-7.
104 International Astronomical Union (2019, 3 June) *IAU Statement on Satellite Constellations*. https://www.iau.org/news/announcements/detail/ann19035/

Additionally, IAU notes worries about the interference of satellite constellations with radio astronomy frequencies. Empirical validation has already confirmed that these concerns are not purely theoretical[105]. On the contrary, despite many mega-constellations still in the development phase with only a fraction of planned satellites already in orbit, the implications are already apparent. The European Southern Observatory estimates its ground-based telescopes could be moderately affected at 0.5-3%[106]. However, as the study suggests, wide-field surveys conducted by large telescopes could see 30-50% of exposures severely affected[107] in the absence of significant mitigation efforts. Addressing these issues is of paramount importance. Astronomy communities and funding agencies "*have ranked wide-field survey telescopes as a top priority for future developments in astronomy*"[108].

Policy Recommendations

The United Nations Office for Outer Space Affairs assigns utmost importance to responsible and transparent conduct in this global commons. By offering a range of recommendations for effectively dealing with the rise of mega-constellations, we seek to contribute to preserving space for the next generations and avoid impeding future scientific efforts.

Image 1: The sky in Germany on the night of the Perseids meteor shower on 12 August 2018.

Note: Most of the dozens of lines are made by satellites reflecting the sunlight from below the horizon. (Credit: Eckhard Slawik).

[105] Walker et al. (2020) *Impact of Satellite Constellations on Optical Astronomy and RecommendationsToward Mitigations*, Bulletin of the AAS. https://doi.org/10.3847/25c2cfeb.346793b

[106] Hainaut, Williams (2020) *Impact of satellite constellations on astronomical observations with ESO telescopes in the visible and infrared domains*. Astronomy & Astrophysics 636, 121. https://doi.org/10.1051/0004-6361/202037501

[107] ibid.

[108] European Southern Observatory (2020) *New ESO Study Evaluates Impact of Satellite Constellations on Astronomical Observations*. https://www.eso.org/public/news/eso2004/

Recommendations: Safety, security and sustainability of the space environment

Individual Stakeholders	National Level	International Level
Improve post-mission disposal compliance.	Develop national rules on large constellations enabling sustainable growth of the space economy.	Utilize the United Nations as a vehicle to seek consensus for policies on multilateral sharing of orbital data as applicable that meet the basic needs of space operators.
Institutionalize sharing of best practices and lessons learned around mega-constellations among space operators	Thorough implementation of existing normative frameworks, including Space Debris Mitigation Guidelines and the Long-term Sustainability of Outer Space Activities.	Conceptualize multilateral solutions to ensure normative frameworks remain fit for purpose.
	Enhanced registration practices to facilitate transparency and trust.	Consider the establishment of a United Nations-based information-sharing mechanism for objects and events in space as the basis for the global space traffic management.
		Harmonize space traffic management practices and regulations.

Recommendations: Protecting ground-based astronomy[109]

Individual Stakeholders	National Level	International Level
Mitigation strategies as a core component of corporate social responsibility.	Formulate satellite licensing requirements and guidelines that consider the impact on stakeholders, including astronomical activities.	Develop international frameworks relating to reflected or emitted electromagnetic radiation from satellites, its impacts on science and efforts to mitigate the deleterious aspects of such impacts.
Establish data policies to enable planning to avoid impacts and post-hoc analysis of incurred impacts.	Investigate policy instruments that account for negative externalities, including astronomical activities. Develop incentives & inducements for industry and investors.	Capacity-building and outreach efforts bringing stakeholders together to discuss and move policy development forward.

[109]Upon request from the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), UNOOSA and Government of Spain, jointly with the International Astronomical Union (IAU), organized an online workshop "Dark and Quiet Skies for Science and Society" in October 2020. Following the workshop, the working groups of the Scientific Organising Committee (SOC) produced a report in January 2021, outlining recommendations to be acted upon either by local governments or agreed to at an international level, aimed at protecting the science of astronomy.

E. Environmentally compatible frontier technologies

Distributed Recycling and Additive Manufacturing for Sustainable Development Goals

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Abstract

The recent global supply chain disruptions and concomitant shortages have clarified the utility of accelerating open source development and distributed manufacturing. In recent years, the release of digital manufacturing tools with open source licenses have radically reduced the costs of manufacturing and increased its accessibility. This has led to a proliferation of free and open source hardware designs, which now number in the millions. These designs can be replicated using digital distributed manufacturing by consumers themselves as well as by small businesses. More recently, open hardware has enabled *distributed recycling and additive manufacturing* (DRAM), where post-consumer waste can be recycled in the home or community into valuable products for less than 1% of commercial costs. In addition, life cycle analysis shows that DRAM is environmentally superior to both conventional recycling and manufacturing. DRAM thus provides an incredible opportunity to reduce the costs of reaching many Sustainable Development Goals (SDGs) by enabling people to make what they need in their communities from abundant waste materials. To capitalize on this opportunity, policy interventions are outlined to set up a Central Open Source Database, where people can freely download vetted designs and expand the Consumer Bill of Rights worldwide, including digital access to material ingredient lists for all consumer products. These two policies will make recycling easier and far more profitable, while reducing poverty and supporting other SDGs.

Empirical Facts and Issues on Open Source as the Fastest Technical Development Method

Free and open source software (FOSS)

The intergovernmental deliberation at the Commission on Science and Technology for Development[1] found that open source methods can overcome barriers to the building and dissemination of the global stock of knowledge, particularly in developing countries. Free and open source software **(**FOSS) is software that is both free software and open-source.[2] With the majority of large companies now contributing to open source software projects,[3] it has become the dominant form of technical development in this sector.[4] All supercomputers[5] and 90% of cloud servers run open source operating systems. (i.e. Every click on Facebook, Twitter, Wikipedia, Youtube or Amazon uses a machine running FOSS.[6]) FOSS is used by 90% of the Fortune Global 500[7], over 84% of the global smartphone market[8], and more than 80% of the "internet of things" devices.[9]

Free and open source hardware (FOSH)

Similarly, free and open source hardware (FOSH) uses the same sharing philosophy[10]. FOSH is hardware

[1] Commission on Science and Technology for Development | UNCTAD https://unctad.org/topic/commission-on-science-and-technology-for-development

[2] "Free" here refers to a user's freedom to use, copy, study, and change the software in any way as well as sell it (https://www.gnu.org/philosophy/free-sw.html) because of the "Open source" or access to the source code following requirements (https://opensource.org/osd). Free software focuses on the fundamental freedoms it gives to users, whereas open source software focuses on the advantages of peer-to-peer technical development model. FOSS is used here to avoid bias towards either political approach. FOSS is available in source code form, and can be used, studied, copied, modified and redistributed without restriction, or with restrictions that only ensure recipients have the same rights.

[3] LeClair, H., 2016. 65% of companies are contributing to open source projects. https://opensource.com/business/16/5/2016-future-open-source-survey

[4] The superiority of FOSS method for software development is well-documented. See:
Raymond, E. (1999). The cathedral and the bazaar. *Philosophy & Technology*, *12*(3), 23.
Lakhani, K. R., & Von Hippel, E. (2003). How open source software works:"free" user-to-user assistance. *Research Policy*, *32*(6), 923-943.
Comino, S., Manenti, F. M., & Parisi, M. L. (2007). From planning to mature: On the success of open source projects. *Research Policy*, *36*(10), 1575-1586.
Lee, S. Y. T., Kim, H. W., & Gupta, S. (2009). Measuring open source software success. *Omega*, *37*(2), 426-438.
Herstatt, C. and Ehls, D., 2015. *Open Source Innovation: The Phenomenon, Participant's Behaviour, Business Implications*. Routledge.

[5] Vaughan-Nichols, S. J. Supercomputers: All Linux, all the time. ZDNet. 2018. https://www.zdnet.com/article/supercomputers-all-linux-all-the-time/

[6] Hiteshdawda. Realising the Value of Cloud Computing with Linux. (2020). https://www.rackspace.com/en-gb/blog/realising-the-value-of-cloud-computing-with-linux

[7] Parloff, R. How Linux Conquered the Fortune 500. Fortune (2013). https://fortune.com/2013/05/06/how-linux-conquered-the-fortune-500/

[8] Smartphone Market Share - OS. IDC: The premier global market intelligence company. 2020. https://www.idc.com/promo/smartphone-market-share

[9] Eclipse. IoT Developer Survey 2019 Results. https://iot.eclipse.org/community/resources/iot-surveys/assets/iot-developer-survey-2019.pdf

[10] Powell, A. (2012). Democratizing production through open source knowledge: from open software to open hardware. *Media, Culture & Society*, *34*(6), 691-708.

whose design is shared so that anyone can study, modify, distribute, make, and sell the design or hardware based on the design.[11] FOSH provides the "source code" for physical hardware including the bill of materials (BOMs), schematics, computer aided designs (CAD), and other information such as detailed instructions needed to recreate a physical item. As well established in FOSS development, FOSH has now demonstrated improved product innovation.[12] FOSH is growing rapidly and trails behind FOSS by about 15 years in the academic literature.[13]

Digital Manufacturing

The explosion of FOSH has been fostered by the rise of digital manufacturing like 3-D printing.[14] 3-D printing gained popularity when the open sourcing[15] of the technology dropped the costs to become accessible.[16] Yet, such low-cost open source 3-D printers are able to fabricate stronger parts of higher quality than proprietary 3-D printers that cost over $20,000.[17] Open source 3-D printers hold particular promise in the developing world.[18] They can fabricate many of their own parts, so can be fixed without access to supply chains, and can be upgraded and evolve under the open-source paradigm.[19] Selecting from millions of free designs, communities can radically reduce costs for a wide range of products by 3-D printing them for themselves, including: children's toys[20], learning aids,[21] drones[22], photovoltaic racking[23] and medical equipment (e.g. clubfoot braces[24], prosthetics[25], self-adjustable glasses[26], and arthritis adaptive aids).[27] The free and open source designs for these products are growing exponentially,[28] already number in the millions, and are currently scattered throughout dozens of repositories.[29]

Thus, combining open source designs with digital distributed manufacturing, it is possible for consumers throughout the world to manufacture their own products for lower costs than those that are mass manufactured. [30]

Gibb, A. (2014). *Building open source hardware: DIY manufacturing for hackers and makers*. Pearson Education.
[11] Open Source Hardware Association (OSHWA). Definition. https://www.oshwa.org/definition/
[12] Dosemagen, S., Liboiron, M., & Molloy, J. (2017). Gathering for Open Science Hardware 2016.
Yip, M. C., & Forsslund, J. (2017). Spurring Innovation in Spatial Haptics: How Open-Source Hardware Can Turn Creativity Loose. *IEEE Robotics & Automation Magazine*, 24(1), 65-76.
[13] Pearce, J., 2018. Sponsored Libre Research Agreements to Create Free and Open Source Software and Hardware. *Inventions*, 3(3), p.44 ; https://doi.org/10.3390/inventions3030044
[14] Gershenfeld, N. *Fab: The Coming Revolution on Your Desktop – from Personal Computers to Personal Fabrication*; Basic Books: New York, NY, 2005.
Bradshaw, S.; Bowyer, A.; Haufe, P. The intellectual property implications of low-cost 3D printing. *ScriptEd*. 2010, 7 (1), 1-27; https://doi.org/10.2966/scrip.070110.5
Weinberg, M. (2010). IT WILL BE AWESOME IF THEY DON'T SCREW IT UP. http://nlc1.nlc.state.ne.us/epubs/creativecommons/3DPrintingPaperPublicKnowledge.pdf
Cano, J. The Cambrian explosion of popular 3D printing. Int. J. of Artificial Intelligence and Interactive Multimedia. 2011, 1 (4), 30-32.
[15] https://reprap.org/wiki/RepRap
[16] Rundle, G., 2014. *A Revolution in the Making*. Simon and Schuster.
The most popular desktop 3-D printer is open source and costs under $200. See: https://www.creality3dofficial.com/products/official-creality-ender-3-3d-printer
[17] Tymrak, B.M., et al., 2014. Mechanical properties of components fabricated with open-source 3-D printers under realistic environmental conditions. *Materials & Design*, 58, pp.242-246. https://doi.org/10.1016/j.matdes.2014.02.038
[18] Pearce, J.M. et al., "3-D Printing of Open Source Appropriate Technologies for Self-Directed Sustainable Development," *Journal of Sustainable Development*, 3(4), 17-29, 2010. https://doi.org/10.5539/jsd.v3n4p17
[19] Arnott, R. The RepRap project – open source meets 3D printing. *Computer and Information Science Seminar Series*. 2008.
Bowyer, A. (2004) Wealth Without Money. RepRap Wiki. Available: http://reprap.org/wiki/Wealth_Without_Money
[20] Petersen, E., et al., 2017. Impact of DIY home manufacturing with 3D printing on the toy and game market. *Technologies,* 5(3), p.45. https://doi.org/10.3390/technologies5030045
[21] Gallup, N. and Pearce, J.M., 2020. The Economics of Classroom 3-D Printing of Open-Source Digital Designs of Learning Aids. *Designs*, 4(4), p.50. https://doi.org/10.3390/designs4040050
[22] Niemand, J., et al. 2020, September. Design and testing of recycled 3D printed foldable unmanned aerial vehicle for remote sensing. In *2020 International Conference on Unmanned Aircraft Systems (ICUAS)* (pp. 892-901). IEEE.
[23] Wittbrodt, B. and Pearce, J.M., 2017. 3-D printing solar photovoltaic racking in developing world. *Energy for Sustainable Development*, 36, pp.1-5. https://doi.org/10.1016/j.esd.2016.08.001
[24] Savonen, B., et al., Open-Source Three-Dimensional Printable Infant Clubfoot Brace, *Journal of Prosthetics and Orthotics:*32(2), 149-158, 2020. https://doi.org/10.1097/JPO.0000000000000257
[25] Zuniga, J.M., et al., 2016. An open source 3D-printed transitional hand prosthesis for children. *Journal of Prosthetics and Orthotics*, 28(3), pp.103-108.
Schmidt, R., et al., 2015. 3D-printed prosthetics for the developing world. In *SIGGRAPH 2015: Studio* (1).
[26] Gwamuri, J., et al. Reversing the Trend of Large Scale and Centralization in Manufacturing: The Case of Distributed Manufacturing of Customizable 3-D-Printable Self-Adjustable Glasses. *Chall. Sustain.* **2014**, 2, 30–40. http://dx.doi.org/10.12924/cis2014.02010030
[27] Gallup, N., et al., 2018. Economic Potential for Distributed Manufacturing of Adaptive Aids for Arthritis Patients in the US. *Geriatrics*, 3(4), p.89. https://doi.org/10.3390/geriatrics3040089
[28] Wittbrodt B, et al., JM (2013) Life-cycle economic analysis of distributed manufacturing with open-source 3-D printers. *Mechatronics* 23(6):713-726.
[29] https://reprap.org/wiki/Printable_part_sources
[30] The profit potential for DIY digital manufacturing is so high that $20 for a kg of commercial plastic filament can 3-D print 20 products that exceed the value of a desktop printer itself and can be printed in a weekend. See:
Petersen, E.E. & Pearce, J.M. Emergence of Home Manufacturing in the Developed World: Return on Investment for Open-source 3-D Printers. *Technologies* 5(1), 7 (2017). http://dx.doi.org/10.3390/technologies5010007

Distributed digital manufacturing of FOSH has shown particular promise among scientists[31] for developing custom scientific tools.[32] FOSH not only provides customized products for doing state-of-the-art experiments, but makes them more accessible to developing world scientists because of deep cost discounts.[33] A 2020 review[34] found FOSH saved 87% compared to proprietary tools, and over 94% if both open source electronics and 3-D printing were used. Savings were found of over 99% for sensors[35], reactors[36], analytical equipment[37] and digital manufacturing equipment[38] (e.g. laser sintering additive manufacturing system[39] or an autosampler[40]).

Most recently, OS technologies have enabled engineers to rapidly design medical devices for domestic distributed production during the pandemic – everything from open source ventilators[41] to personal protective equipment (PPE) like face shields[42] and masks[43]. In the U.S., the National Institutes of Health (NIH), for example, used their open source 3D Print Exchange to review free designs for clinical and community use.[44]

Distributed Recycling and Manufacturing (DRAM)

One of the most promising sustainable development opportunities that open hardware has enabled recently is distributed recycling and additive manufacturing (DRAM).[45] Several technological pathways[46] shown in Box 1 allow individuals to recycle waste plastic by 3-D printing it into valuable products.[47] DRAM starts with waste plastic that is produced everywhere from packaging to broken products. It is washed, dried, and then ground or cut into particles using a waste plastic granulator[48] or office shredder. Next, the particles are either converted to 3-D printing filament using a recyclebot[49] or printed directly. Filament made with a recyclebot costs less than $0.10/kg, whereas commercial filament costs $20/kg or more. DRAM can produce valuable products at remarkably low costs. For example, using **a recyclebot/3-D printer combination can produce over 300 products for the same price as on Amazon.com**.[50]

This process can also be solar powered directly, making it accessible even to those without reliable electricity and greening the technology further.[51]

The second approach skips making filament and uses fused particle fabrication (FPF) or fused granule fabrication (FGF) to directly 3-D print waste plastic into

[31] Canessa, E., Fonda, C., Zennaro, M. and Deadline, N., 2013. *Low--cost 3D printing for science, education and sustainable development*. Low-Cost 3D Printing, 11.
[32] Pearce, J.M., 2012. Building research equipment with free, open-source hardware. *Science*, *337*(6100), 1303-1304.
Pearce, J.M., 2013. *Open-source lab: how to build your own hardware and reduce research costs*. Elsevier.
[33] There are many studies that document enormous economic savings with FOSH see:
Baden, T. et al. 2015. Open Labware: 3-D printing your own lab equipment. *PLoS Biology* 13(3) p.e1002086. https://doi.org/10.1371/journal.pbio.1002086
Fisher, D.K. & Gould, P. J. Open-source hardware is a low-cost alternative for scientific instrumentation and research. *Modern instrumentation* (2012).
Pearce. J.M. Impacts of Open Source Hardware in Science and Engineering. *The National Academy of Engineering: The Bridge*. 47 (3), 24-31, 2017.
Damase, T.R., et al., 2015. Open source and DIY hardware for DNA nanotechnology labs. *Journal of Biological Methods*, 2(3), p.e24.
[34] Pearce, J.M., 2020. Economic savings for scientific free and open source technology: A review. *HardwareX*, 8, p.e00139.
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[37] Pereira VR, Hosker BS. Low-cost (<€5), open-source, potential alternative to commercial spectrophotometers. *PLOS Biology*. 2019 juin;17(6):e3000321.
[38] Pusch K, Hinton TJ, Feinberg AW. Large volume syringe pump extruder for desktop 3D printers. *HardwareX*. 2018;3:49–61.
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[40] Carvalho MC, Murray RH. Osmar, the open-source microsyringe autosampler. *HardwareX*. 2018;3:10–38.
[41] Pearce. J.M. 2020. A review of open source ventilators for COVID-19 and future pandemics. *F1000Research*, 9:218 https://f1000research.com/articles/9-218/v2
[42] Prusa. 2020. 3D Printed face shields for medics and professionals. https://www.prusa3d.com/covid19/
[43] Free Sewing, 2020. Calling all makers: Here's a 1-page PDF facemask pattern; Now go make some and help beat this thing. https://freesewing.org/blog/facemask-frenzy/
[44] https://3dprint.nih.gov/collections/covid-19-response
[45] Sanchez, F.A.C., et al. 2020. Plastic recycling in additive manufacturing: a systematic literature review and opportunities for the circular economy. *Journal of Cleaner Production*, p.121602. https://doi.org/10.1016/j.jclepro.2020.121602
[46] Dertinger, S.C., et al. 2020. Technical pathways for distributed recycling of polymer composites for distributed manufacturing: Windshield wiper blades. *Resources, Conservation and Recycling*, 157, p.104810. https://doi.org/10.1016/j.resconrec.2020.104810
[47] Sanchez, F.A.C., et al. 2015, August. Polymer Recycling and Additive Manufacturing in an Open Source context: Optimization of processes and methods. In Annual international solid freeform fabrication symposium, ISSF 2015 (pp. 1591-1600).
[48] Ravindran, A., et al., 2019. Open Source Waste Plastic Granulator. *Technologies*, 7(4), p.74. https://doi.org/10.3390/technologies7040074
[49] https://www.appropedia.org/Recyclebot Note: recyclebots can be 3-D printed themselves: Woern, A.L., et al. 2018. RepRapable Recyclebot: Open source 3-D printable extruder for converting plastic to 3-D printing filament. *HardwareX*, 4, p.e00026. https://doi.org/10.1016/j.ohx.2018.e00026
[50] Zhong, S. and Pearce, J.M., 2018. Tightening the loop on the circular economy: Coupled distributed recycling and manufacturing with recyclebot and RepRap 3-D printing. *Resources, Conservation and Recycling*, *128*, pp.48-58. https://doi.org/10.1016/j.resconrec.2017.09.023
[51] Zhong, S., et al. 2017. Energy payback time of a solar photovoltaic powered waste plastic recyclebot system. *Recycling*, *2*(2), p.10. https://doi.org/10.3390/recycling2020010

products at the large scale[52] and on the desktop.[53] Both approaches work over a wide range of plastics, including the most common one, PET (e.g. water bottles).[54]

Box 1: How DRAM Works

Two approaches to turning waste plastic into consumer goods with DRAM. Waste plastic is first converted to filament in a vertical recycle-bot and then 3-D printed into components for a camera tripod using a 3-D printer.

Or the shredded waste plastic is directly 3-D printed using fused particle fabrication to make a skateboard deck, which was converted into an electric-skateboard (as shown) using open source plans.

[52] Woern, A.L., et al. 2018. Fused particle fabrication 3-D printing: Recycled materials' optimization and mechanical properties. *Materials*, 11(8), p.1413. https://doi.org/10.3390/ma11081413

[53] Alexandre, A., et al., 2020. Mechanical Properties of Direct Waste Printing of Polylactic Acid with Universal Pellets Extruder: Comparison to Fused Filament Fabrication on Open-Source Desktop Three-Dimensional Printers. *3D Printing and Additive Manufacturing*. http://doi.org/10.1089/3dp.2019.0195

[54] Little, H.A., et al. 2020. Towards distributed recycling with additive manufacturing of PET flake feedstocks. Materials, 13(19), p.4273. https://doi.org/10.3390/ma13194273 and Zander, N.E., Gillan, M., Burckhard, Z. and Gardea, F., 2019. Recycled polypropylene blends as novel 3D printing materials. *Additive Manufacturing*, *25*, pp.122-130. https://doi.org/10.1016/j.addma.2018.11.009

Lastly, 3-D printed waste molds[55] can be used to recycle composites or hard-to-print plastics.[56] Overall, both recycling[57] and 3-D printing[58] via DRAM are substantially better for the environment. With a pandemic interrupting global supply chains[59], making products at home from waste is even more appealing.

France is already investigating making small businesses that collect plastic waste at schools to make 3-D filament.[60] The return on investments (ROIs) for small companies or fab labs making custom products is substantial.[61] The ROI for the global community for the development of FOSH is much greater and can be calculated from the downloaded substitution value.[62] To understand how powerful this approach is, consider a simple open source syringe pump library design[63] that had ROIs for funders ranging from 100s to 1,000s of a percent after only a few months[64], and created derivatives[65] which have applications in digital manufacturing, science, medicine and STEM education. The primary barriers to further DRAM use are the lack of a trusted Central Open Source Database (COSD) and incomplete labeling of products.

Policy Recommendations

Policy 1

There are millions of open source technologies scattered over various websites and there is no comprehensive database of free and open technologies. Therefore, a trusted centralized authority providing a platform of free and open source technologies could potentially accelerate discovery and innovation across all sectors associated with the SDGs[66], while minimizing IP barriers and accelerating DRAM adoption. The efficacy of this approach on a limited scale was witnessed by the COVID-19 PPE shortage in the U.S. that was solved in part by an agreement[67] by a collection of government agencies led by the NIH to accelerate distributed manufacturing of 3-D printed protective gear for COVID-19 response.[68] Users share and find designs that are clinically relevant and readily compatible with distributed digital manufacturing. Similarly, for a global COSD to be most effective, it needs to be housed in a trusted central authority: the UN. The UN already has established a leadership role in advocating open source technology for the member countries.[69] The UN establishing a COSD would provide direct access to needed information to produce products for everyone.

Policy 2

Expand the U.S. Consumer Bill of Rights[70] to the globe and include digital access to material ingredient lists for all consumer products. The core advantages to supporting intentional policy to freely accessible information about the material ingredients for all consumer goods[71]: 1) creating new business opportunities for upselling products manufactured with

[55] Reich, M.J., et al. 2019. Mechanical properties and applications of recycled polycarbonate particle material extrusion-based additive manufacturing. Materials, 12(10), p.1642. https://doi.org/10.3390/ma12101642

[56] Mohammed, M.I., et al., 2018, November. EcoPrinting: investigation of solar powered plastic recycling and additive manufacturing for enhanced waste management and sustainable manufacturing. In *2018 IEEE Conference on Technologies for Sustainability (SusTech)* (pp. 1-6). IEEE.

[57] Kreiger, M. et al., 2014. Life cycle analysis of distributed recycling of post-consumer high density polyethylene for 3-D printing filament. *Journal of Cleaner Production*, *70*, pp.90-96. https://doi.org/10.1016/j.jclepro.2014.02.009

[58] Kreiger, M. and Pearce, J.M., 2013. Environmental life cycle analysis of distributed three-dimensional printing and conventional manufacturing of polymer products. *ACS Sustainable Chemistry & Engineering*, *1*(12), pp.1511-1519. https://pubs.acs.org/doi/abs/10.1021/sc400093k

[59] Soergel, A. Coronavirus Outbreak Throws Future of Global Trade Into Question. US News & World Report https://www.usnews.com/news/best-countries/articles/2020-04-10/coronavirus-outbreak-throws-future-of-global-trade-into-question

[60] Santander, P., et al. 2020. Closed loop supply chain network for local and distributed plastic recycling for 3D printing: a MILP-based optimization approach. *Resources, Conservation and Recycling*, *154*, p.104531. https://doi.org/10.1016/j.resconrec.2019.104531

[61] Byard, D.J., et al. 2019. Green fab lab applications of large-area waste polymer-based additive manufacturing. *Additive Manufacturing*, 27, pp.515-525. https://doi.org/10.1016/j.addma.2019.03.006

[62] Pearce, J.M., 2015. Quantifying the value of open source hardware development. *Modern Economy*, 6, pp.1-11.

[63] Wijnen, B., et al. (2014) Open-source syringe pump library. *PloS One*, 9(9), p.e107216. https://doi.org/10.1371/journal.pone.0107216

[64] Pearce, J.M., 2016. Return on investment for open source scientific hardware development. *Science and Public Policy,* 43(2), pp.192-195. https://doi.org/10.1093/scipol/scv034

[65] Klar, V., et al., 2019. Ystruder: Open source multifunction extruder with sensing and monitoring capabilities. *HardwareX*, 6, p.e00080. https://doi.org/10.1016/j.ohx.2019.e00080

[66] THE 17 GOALS | Sustainable Development https://sdgs.un.org/goals

[67] https://www.fda.gov/about-fda/domestic-mous/mou-225-20-008

[68] https://www.nextgov.com/emerging-tech/2020/03/fda-nih-va-partner-accelerate-3d-printed-protective-gear-covid-19-response/164246/

[69] See for example:
E-Commerce and development report 2003. United Nations. https://unctad.org/system/files/official-document/ecdr2003_en.pdf
UNCTAD (Ed.). (2012). *The software industry and developing countries*. https://unctad.org/system/files/official-document/ier2012_en.pdf

[70] Kennedy, J.F. Special message to the Congress on protecting the consumer interest, Public papers of the presidents of the United States 93 (1962) 236. Available online: http://www.presidency.ucsb.edu/ws/?pid=9108.

[71] Pearce, J.M. Expanding the Consumer Bill of Rights for material ingredients. *Materials Today* 21(3), pp. 197-198 (2018). DOI: https://doi.org/10.1016/j.mattod.2018.02.002

superior materials, 2) improving consumer safety, 3) enabling purchasing consistent with consumer values, 4) fostering advanced industrial recycling, as well as DRAM and 5) enabling advanced uses of advanced resource tracking in the UN COSD. This enables the COSD to operate like a recipe program where the users input their available resources and the COSD outputs solutions that fit their specific needs. As communities recreate, review, and revise innovations, the COSD can use machine learning about their accessibility to resources as well. The more communities that utilize the system, the more the database knows about the availability of resources like materials, tools, and skills throughout the world and the more adaptive and appropriate the search results can become. Thus, this application increases its value not only with each additional user, but also with each additional use.

Impacts of new Internet applications and artificial intelligence on global energy demand – an issue of concern?

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Note: The views expressed are those of the authors and do not necessarily reflect those of the United Nations or its senior management.

Abstract

The energy demand of Internet applications and artificial intelligence – while relatively small in the past – has already become significant and continues to increase unabatedly. These technologies are key to "smart" energy systems and overall energy efficiency. However, they also continue to lead to entirely new services, most of which are not geared toward increasing efficiencies of the socio-technical system – hence further increasing global energy demand. Currently, the energy efficiency of current silicon-based computing is at least 10,000 to 100,000 times lower than human brains. Against this background, it is a matter of concern that the energy efficiency of the computers, the Internet and deep neural network-based AI applications (which will replace and complement human cognitive work) has reached fundamental limits, while overall computing performance and usage increases unabated. The most likely overall result will be accelerated, increased energy demand for the Internet and AI in the coming decades, unless sufficiency considerations fundamentally change the current direction.

The fast pace of technological change in recent years in robotics, artificial intelligence (AI), 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 telecommunications and information and communication technologies (ICT). On the one hand, these emerging technologies hold great promise for a range of high-efficiency energy and water systems that could be deployed in all countries and catalyse the global move towards sustainability. On the other hand, despite efficiency increases, these technologies and especially AI will require ever-increasing electricity and mineral resources with its associated pollution and wastes (e.g., e-waste, nano-waste, and chemical wastes). This might be especially the case, since these new technologies make entirely new services possible, many of which are not geared toward increasing the efficiency of the existing socio-technical system. When fundamental limits to increased energy efficiency of silicon-based computing are also considered, it is evident that additional non-efficiency enhancing applications will continue increasing energy demand, unless strict sufficiency considerations or energy use limits are introduced.

Significant and increasing overall energy demand of Internet and AI

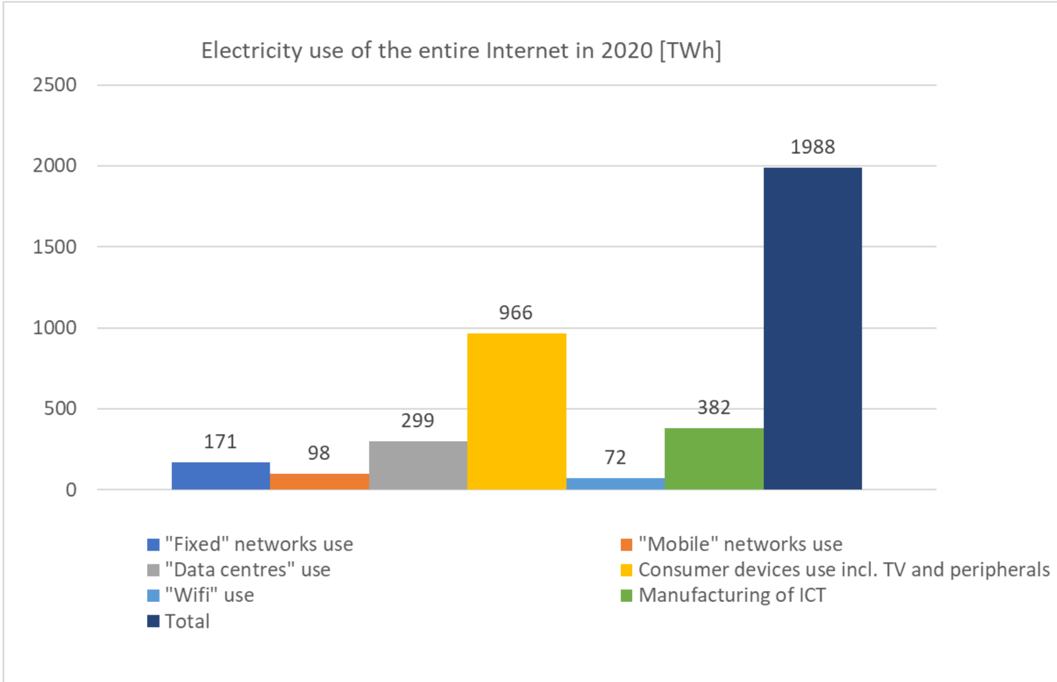
Digital technologies hold great potential for creating environmental benefits in many sectors, but they themselves are also rapidly emerging as important drivers of overall energy demand, energy mix and environmental pollution[1], especially when a life-cycle perspective is taken to ICT. The following key categories of electricity use of ICT need to be taken into account: (a) consumer devices, including personal computers, mobile phones, TVs and home entertainment systems; (b) network infrastructure; (c) data centre computation and storage; and (d) production of the above categories.[2]

The Internet has become truly pervasive. As of Jan. 2021, of the 7.8 billion people in the world, there were 4.8 billion Internet users, 2.7 billion Facebook users, 1.8 billion Websites, and 370 million active Twitter users.[3] In a typical day in Jan. 2021, there were 265 bill. emails, 794 mill. tweets, 7.5 bill. youtube videos watched, 155 mill. Tumblr posts, 453 mill. skype video calls, 89 mill. videos uploaded. Internet traffic reached an incredible 9.4 bill. GB/day. On that day, 4.3 mill. smart phones and 0.7 mill. Computers were sold.

[1] For a recent literature review and expert survey, please see Roehrl, R. (2019). Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system. SLP/TFM research paper, December 2019.

[2] Andrae, A. and Edler, T.E., (2015). On Global Electricity Usage of Communication Technology: Trends to 2030. Challenges 2015, 6, 117-157; doi:10.3390/challe6010117

[3] Data source: Internetlivetstats.com



Source: Roehrl (2019) [1]*, based on data reported* by Andrae[2,3,4] . *Note*: This estimate for 2020 was made at the end of 2019.

How much energy did this take? The best guess, peer-reviewed estimate of energy used by the entire global Internet was estimated to be about 1,988 TWh or 7.2 EJ for the year 2020 (see figure), which was equivalent to about 9 per cent of total global electricity use. Roughly half of the total, or 966TWh, was due to consumer devices, such as computers, mobile phones, laptops and TVs. The remainder (1,022 TWh) was due to local, fixed and mobile networks, data centres, and the manufacturing of the various components. Excluding consumer devices, the remainder alone caused emissions of about 949 MtCO_2 in 2019.

The mobile networks component, in particular, is expected to rapidly increase with the advent of 5G and mobile video streaming services. It is important to note the estimates for 2020 presented in the figure were made at the end of 2019 and that actual numbers may actually have been around 40% higher due to digital response strategies to the pandemic!

The production of these devices and other ICT components are highly energy- and resource-intensive. For example, the energy production footprint of all smartphones in the world was about 30 per cent larger than that of all passenger cars and is expected to continue to an increase in line with more rapidly increasing numbers of smartphones than cars. It is estimated that it takes more energy to create a computer than it takes to run the computer for its entire working lifetime.[5] The short product life cycle of electronic products is the prime culprit.

Online video streaming has shown to have a noticeable impact on carbon emissions, as a significant level of electricity is needed to sustain the data flows associated with the streaming process. It is estimated that globally video streaming accounts for annual carbon emissions equivalent to that of Spain.[6] Much of this is due to mobile data use, a component that is expected to increase rapidly with the deployment of 5G networks.

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[1] Roehrl, R. (2019). Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system. SLP/TFM research paper, December 2019.

[2] Andrae, A. (2019). Comparison of Several Simplistic High-Level Approaches for Estimating the Global Energy and Electricity Use of ICT Networks and Data Centers. International Journal of Green Technology, 2019, 5, 50-63.

[3] Andrae ASG, Edler T. (2015). On global electricity usage of communication technology: trends to 2030. Challenges 2015; 6: 117-57. https://doi.org/10.3390/challe6010117

[4] Andrae ASG (2019b). Projecting the chiaroscuro of the electricity use of communication and computing from 2018 to 2030. [cited 2019 Sept 25]: https://www.researchgate.net/publication/331047520_Projecting_the_chiaroscuro_of_the_electricity_use_of_communication_and_computing_from_2018_to_2030

[5] Estimates from a UNU study. Link: https://www.eurekalert.org/pub_releases/2004-03/tca-uss030204.php

[6] Efoui-Hess, M. 2019. Climate Crisis: The unsustainable use of online video - the practical case for digital sobriety. The Shift Project.

Looking towards the next ten years, artificial intelligence and especially deep learning neural networks are expected to become an important driving factor for increasing energy demand and GHG emissions. Already in 2019, the overall energy use and CO_2 emissions of training every single state-of-the-art deep learning neural network (DNN) consumed an estimated 656 MWh. It was also responsible for 313 t of CO_2 emissions, about as much as five-passenger cars emit over their entire lifetimes.[1] These algorithms rely on vast amounts of data that are stored in data centres.

Bottom-up estimates (based on the number of computations) for data centers' energy use in 2030 range from a five-fold increase (from 200 to 1,000 TWh) up to a fourteen-fold increase to roughly 4,900 TWh. Much if not most of this increase will be due to AI applications.

A recent expert survey showed that a majority of experts and scenario analysts expect an increase of global energy demand over and above the dynamics-as-usual trends until 2030.[2] A minority of experts (20%) expect a decrease and almost one third (30%) of respondents highlight the uncertainty factors.

"Smart" systems increasing efficiency

ICT in general and AI in particular will have applications and impacts in almost all aspects of the global energy system, supply (mining and production), power plants and utilities, final distribution, and end-user devices. It is also increasingly used for modelling of the energy system and even climate modelling, promising significant improvements in accuracy and flexibility of approaches and data acquisition.

Wilson et al. (2018)[3] report on the perceived disruptiveness and emissions reduction potentials for 99 low carbon innovations, in mobility, food, buildings & cities, as well as energy supply and distribution. He also provides estimates of the resulting CO_2 emissions reductions that could be realized through these innovations in the UK in the coming decade. For example, smart heating controls in buildings could reduce emissions by 1.2 to 2.3%, and smart appliances (fridges) could reduce emissions by 0.1%. Car clubs could reduce emissions by 0.8 to 0.9% and e-bikes and e-bike sharing by less than 0.1%.

AI applications are ideally suited for resource discovery and increasing the efficiency of *mining operations*, in view of large amounts of structured data (good example: fracking).[4] "*Machine learning systems can improve the ability to map and understand the size and value of underground deposits of oil and gas—in turn, making it easier to tap those resources at lower cost.*"[1]

Deep learning neural networks can support optimizing the design and operation of wind and solar farms, making them much more efficient. Solar and wind forecasting has the potential to increase efficiencies of these systems.[1]

There are several high impact areas to use AI in utilities and power plants, in order to optimize generation, improve resilience and reduce operating costs.[5] "*Machine learning, sensors and hybrid energy storage… maximize generation efficiency"* [1] by permitting near real-time adjustments. Machine-learning enabled forecasting with hybrid energy storage maximize the use of intermittent renewables by anticipating and reacting to supply and demand peaks.[1] "*Smart wires combined with machine learning to enable real-time power dispatching, and optimize it to current grid load and to buildings' asset portfolios. Drones and insect-sized robots identify defects, predict failures, and inspect assets [including power lines] without interrupting production.*" [1]

AI has been heralded by energy technology companies as key element in smart power systems and networks, by supporting the seamless integration of intermittent modern renewables, such as wind and solar, and reducing energy storage needs. However, for this study no quantitative estimates in this regard have been found from a reliable source.

The potential impact of AI is most likely biggest on the demand/consumer side, simply because of the existing large inefficiencies especially from final to useful energy. Hence, there is a need for new energy technology modelling approaches that take a consumer

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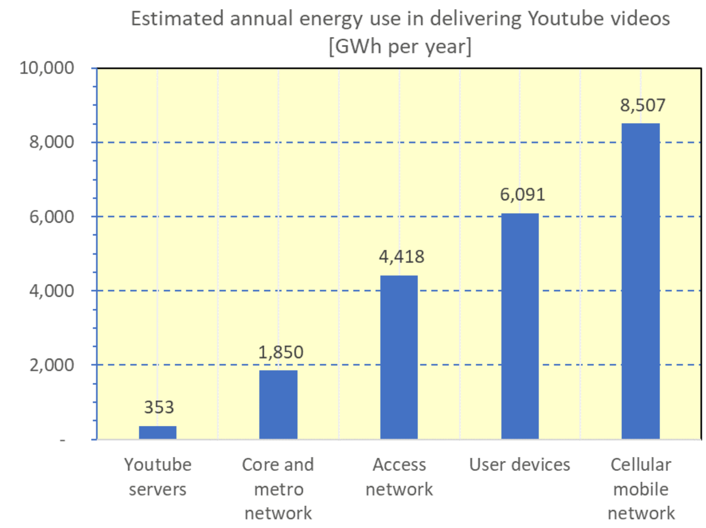
[1] Strubell, E., Ganesh, A., McCallum, A., (2019). Energy and Policy Considerations for Deep Learning in NLP. arXiv:1906.02243v1 [cs.CL] 5 Jun 2019.
[2] Please see Roehrl, R. (2019). Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system. SLP/TFM research paper, December 2019,
[3] Wilson, C., Pettifor, H., Cassar, E., Kerr, L., Wilson., M., (2018). The potential contribution of disruptive low-carbon innovations to 1.5C climate mitigation, Energy Efficiency, https://doi.org/10.1007/s12053-018-9679-8.
[4] Victor, D.G., (2019). How artificial intelligence will affect the future of energy and climate. Brookings institution report. 10 January 2019. Series: A Blueprint for the Future of AI: 2018-2019. https://www.brookings.edu/research/how-artificial-intelligence-will-affect-the-future-of-energy-and-climate/
[5] Bilodeau, S., (2019). The 4x4 Possibilities: 4 Smart Ways to Use AI in 4 Areas of Utilities' Operation. Chairman and Chief Technology Officer at Novacab Inc., 22 July 2019. https://www.energycentral.com/c/iu/4x4-case-4-smart-ways-use-artificial-intelligence-4-areas-utility

and demand-side perspective and that include explicitly energy flows of prime importance for understanding new ICT and AI development constraints.

Entirely new services that are not enhancing energy efficiency

Human ingenuity and perceived needs will drive the supply and demand for new services, many of which will have not beneficial effect on the global energy efficiency. Let us look at just one example: watching YouTube videos on a mobile phone. Preist et al. (2019) provide a detailed analysis of the energy and CO_2 emissions from watching YouTube videos.[1] Youtube servers themselves only consumed 353 GWh per year,[2] whereas the use of core and metro networks (1,850 GWh per year), access networks (4,418 GWh per year), user devices (6,091 GWh per year), and especially cellular networks (8,507 GWh per year) are using many times more energy to watch those Youtube videos (see figure). Hence, streaming the video on the mobile phone is vastly more energy consuming and emissions creating than watching it on LAN-connected computer, especially close to backbone network. In fact, moving to the next generation 5G mobile networks[3] are expected to greatly increase the energy and climate footprint of online video streaming, due to much higher bandwidth available.

An even higher impact could be new video gaming streaming. According to the New Scientist Magazine, Google launched its Stadia streaming service which allows video gaming with a wifi controller, instead of a computer or a game console. Due to the streaming and especially if this will be streamed on mobile phone networks, this new service like many others that are being planned are poised to greatly increase energy use and GHG emissions.



Source: Roehrl (2019) [4], based on data reported in Preist et al. (2019)

Fundamental limits to energy efficiency of computing

According to Moore's law, the number of transistors in a dense integrated circuit (and hence computing power) has doubled about every two years ever since 1970. According to Moore's second law (or Rock's law) the capital cost of a semiconductor fab also increases exponentially over time. Ray Kurzweil quantitatively illustrated the continued exponential growth of computing ever since 1900, well before the advent of digital technology.[5] The question is whether or for how long this exponential growth will continue. In fact, almost technologies appear to progress at exponential rates, at least at certain points in time – this is nothing extraordinary. However, many of the technologies ultimately reach saturation and thus follow an S-shaped progress over time, similar to growth of living species in general. It is unclear whether there are exponential technologies that are fundamentally different, essentially leading to a singularity, most likely in the form of a major structural shift, or whether its exponential growth phase in these cases is simply extended over many more orders of magnitude.

Since around 2012, a slowdown of Moore's Law and Dennard Scaling has been observed. Transistors are not

[1] Chris Preist, Daniel Schien, and Paul Shabajee. 2019. Evaluating Sustainable Interaction Design of Digital Services: The Case of YouTube. In Proceedings of CHI Conference on Human Factors in Computing Systems Proceedings, Glasgow, Scotland UK, May 4–9, 2019 (CHI 2019), 12 pages. https://doi.org/10.1145/3290605.3300627

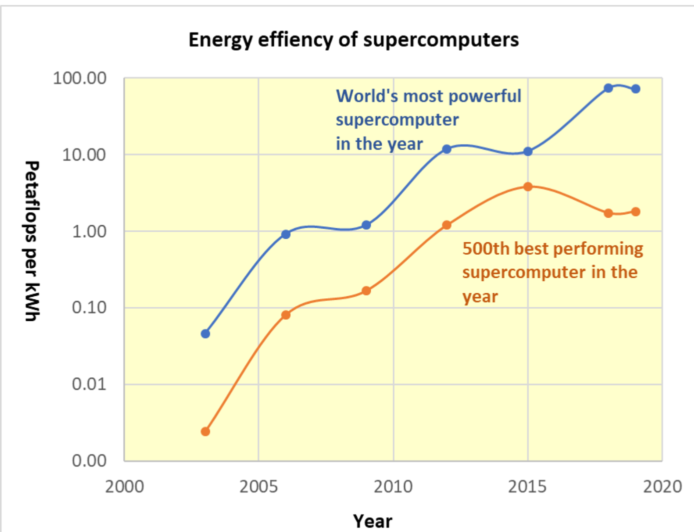
[2] According to some estimates, 10 MtCO2 emissions are due to Youtube servers alone.

[3] which are currently rolled out only in China and the Republic of Korea

[4] Roehrl, R. (2019). Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system. SLP/TFM research paper, December 2019.

[5] Ray Kurzweil (2015). The singularity is near: when humans transcend biology.

getting more efficient, and as a result, general purpose microprocessors are not getting faster nor more efficient (Sze, V., 2019). [1] On the other hand, supercomputers have continued to increase their performance along an exponential law. We are only now entering artificial intelligence territory, whereas before computing power was vastly inadequate. By 2014, the top supercomputer for the first time ever reached 20 Petaflops is roughly the hardware-equivalent of the human brain, according to Kurzweil (1999) [2]. By the end of 2019 (today), the top supercomputer has a peak performance of about 201 Petaflops which is equivalent to 10 brains, the top500 supercomputers combined roughly as much as 50 brains. By 2025, the top supercomputer will be equivalent to 500 brains and by 2030 maybe around 10,000 brains, by 2040 similar to 700,000 brains, etc.



Source: Roehrl (2019) [3], based on data in TOP500 list. [4]

The top performing supercomputer shows exponential performance improvement in terms of energy efficiency over the past two decades (see figure). It reached 72 Petaflops per kWh in November 2019. It also shows that the lower performing supercomputers tended to be less efficient by about an order of magnitude. The total annual electricity consumption of the top supercomputers in each year increased from 12.6 GWh in 2006 to 88.4 GWh in 2019. Hence, even though the energy efficiency improved by a factor of 10 ever 5 years or so, the absolute electricity consumption continued to rapidly increase. Hence, the rapid emergence of supercomputers as significant contribution to world energy consumption.

Deep learning neural networks (DNN) are the one artificial intelligence (AI) technology that has led to the current hype about AI in the private sector and even the general public. This highly data- and computing-intensive technology has only recently become practical, due to much larger amounts of data, orders of magnitude increased supercomputing power and new hardware.

A state-of-the-art DNN model for facial recognition, as described for example by Strubell[5], requires 656 MWh for the training phase, leading to 313 tonnes of CO_2 emissions. It has a 1.52 KW power requirement for 274,120 hours parallel computing costing an incredible US$1 to 3 million in cloud computing expenses. The electricity cost for training accounts around 10% of the overall expenses. In other words, deep learning is a highly energy-intensive business. In fact, as running more and bigger models improves accuracy but greatly increases energy consumption, energy has increasingly become an important limiting factor. The reason for the above estimate is that it aims at human-level accuracy and DNN's are currently vastly less efficient than human brains which consume a mere 25W and would solve the above problem in seconds.

Hence, the human brain is many orders of magnitude more energy efficient than state of the art DNN. Replacing human cognition with current DNN technology would thus quickly run into serious global energy constraints. This would even be the case when at the expense of precision, a less energy-intensive DNN were used. In any case, the energy efficiency of current silicon-based computing is at least an estimated four to five orders of magnitude (i.e., a factor of 10,000 to 100,000) lower than human brains. Organic computers and DNN chips might emerge by the mid-2020s that are slower but with much higher energy efficiencies, which is highly speculative, though.

It is important to note that in DNN there is a training phase that is followed by an inference phase in the actual use of the DNN. Hence, this becomes a problem in sofar as there will be many different types of tailored AI

[1] Sze, V., (2019). Efficient Computing for AI and Robotics. MIT lecture. May 2019.
[2] According to Flow genome Project founder Steven Kotler. See: Diamandis, P.H. and Kotler, S., (2015). Bold: How to Go Big, Create Wealth and Impact the World, Simon & Schuster, ISBN-10: 1476709564.
[3] Roehrl, R. (2019). Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system. SLP/TFM research paper, December 2019
[4] https://www.top500.org/statistics/perfdevel/
[5] Strubell, E., Ganesh, A., McCallum, A., (2019). Energy and Policy Considerations for Deep Learning in NLP. arXiv:1906.02243v1 [cs.CL] 5 Jun 2019.

applications, unless the energy efficiency of DNN is drastically improved. It is even more serious, as further improvements in energy efficiency of DNN will require co-design of specialized hardware and software for different applications, due to the break-down of Moore's law. Previously, further minituarization led not only to higher computing performance but also higher efficiencies, but this development has reached an end, as transistors are on the order of merely a few atoms today.

To take one example, today's self-driving car prototypes use an enormous amount of power for the AI-based navigation system. For example, in 2018, self-driving car prototypes typically used an estimated 2,500 Watts of computing power. Cameras and radar alone generate about 6 GBytes of data every 30 seconds. Some prototypes even need water cooling, since the generated heat is so large.[1] This is not practical.

Most recently, the Navion test chip can achieve localization (i.e., the AI can localize objects in 3D) at under 25mW. This is 65 nm CMOS test chip (4 by 5 mm) with 250 configurable parameters to adapt to different sensors and environments.[2] It is the first chip that performs complete visual inertial odometry. It consumes 684 times and 1,582 times less energy than mobile and desktop CPUs, respectively. Navion enables a class of low energy robotics that uses less than one 1 Watt to interact with the real world. Examples include applications for air quality monitoring; miniature satellites for deep space exploration, and origami robots for medical applications. In all these cases the actuation and computation power is low. These are ingenious innovations, but further improvements will be limited by fundamental Moore's law breakdown.

Future energy demand and the need for sufficiency considerations

Grubler et al. (2019)[3] describe a pioneering, global low energy demand (LED) scenario which meets the 1.5 °C climate target as well as many sustainable development goals, without relying on negative emission technologies, such as bioenergy with carbon capture and storage. By 2050, their fully quantitative scenario reaches a global final energy demand 245 EJ (i.e., 40% lower than today), despite rises in population, income and activity. This much lower global energy system dramatically improves the feasibility of a low-carbon supply-side transformation. The LED scenario explores new social, behavioral and technological innovations.

Many if not most of these efficiency increases presumes AI or similar technologies that might have the potential to accelerate technological progress. Yet again, the AI energy consumption itself is not being considered in the scenario. However, the achieved energy demand reductions in all sectors are so large they would likely pale in comparison to even most high AI energy demand scenarios. For example, in the scenario shared and 'on-demand' fleets of more energy efficient electric vehicles with increased occupancy could reduce global energy demand for transport by 60% by 2050. Intelligent smartphones could nudge preferences towards services and against ownership. Energy performance standards of buildings could reduce energy demand from heating and cooling by 75% by 2050. Low meat diets could reduce agricultural emissions w*hile increasing forest cover*. In the scenario there is a strong emphasis on electrification and current rates of renewable energy deployment would suffice to meet future energy needs.[1]

Anders Andrae and colleagues have carried out pioneering work on the future electricity demand of various ICT system components until 2030, starting with a much-cited 2015 paper on pathways between best and expected for the whole ICT and entertainment[4] and this year's bottom-up estimates on semiconductors[5], and on high-level estimates with simple metrics.[6] Some of these estimates were also discussed in the response to the survey question.

The figure below compares a number of scenarios of ICT energy use by 2030 with that of 2015. Most of these estimates are based on a framework of transistor physics and various roadmaps. It shows an enormous range of possible outcomes, but in any case the

[1] Wired Magazine, Feb. 2018.

[2] http://navion.mit.edu

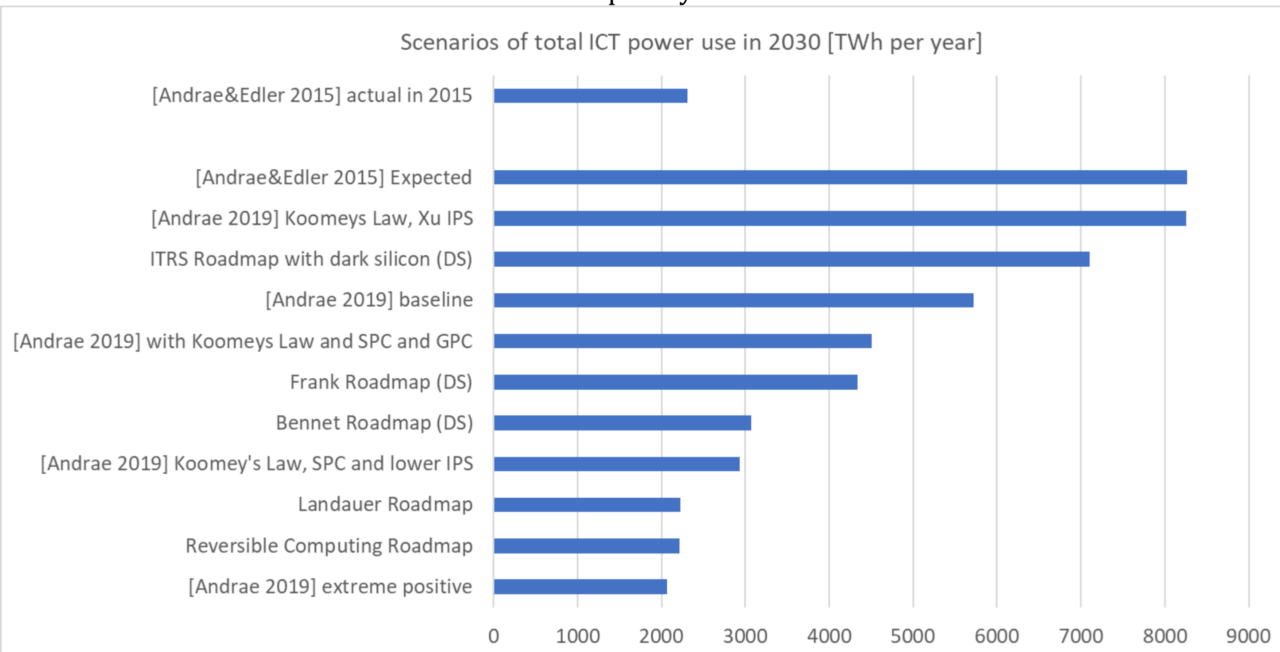
[3] Grubler A , Wilson C , Bento N, Boza-Kiss B, Krey V , McCollum D, Rao N , Riahi K , et al. (2018). A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. Nature Energy 3 (6): 517-525. DOI:10.1038/s41560-018-0172-6.

[4] Andrae, A.S.G., Edler, T. (2015). On Global Electricity Usage of Communication Technology: Trends to 2030, Challenges 2015, 6(1), 117-157; https://doi.org/10.3390/challe6010117.

[5] Andrae, A.S.G. (2019). Prediction studies of the electricity use of global computing in 2030. Int J Sci Eng Investigations, 8 (86) 27-33. http://www.ijsei.com/papers/ijsei-88619-04.pdf

[6] Andrae, A.S.G. (2019). Comparison of Several Simplistic High-Level Approaches for Estimating the Global Energy and Electricity Use of ICT Networks and Data Centers. Int J Green Technol 5 (1) 50-63. https://ijgtech.com/ijgtv5a6/

electricity use will reach anywhere between 2,067 and 8,265 TWh in the year 2030. It would make sense to revisit the LED scenario[1] for 2050 above and explicitly build into the model AI and other new technology components.



Source: Roehrl (2019) [1], based on data by Andrae (2019).[2,1]

Conclusion

Energy demand is closely interrelated to anthropogenic climate change and other global environmental issues. Indeed, it can be used as an imperfect proxy for many environmental issues, even though solutions, of course, go beyond that sector.

The energy demand of AI and related ICTs and their associated GHG emissions – while relatively small in the past – has already become significant and continues to increase unabated. The pandemic further accelerated a digitalization trend that was already accelerating before.

These technologies are key to “smart” energy systems and decisive for further increasing overall energy system efficiencies.

At the same time, they will continue to enable many entirely new services, most of which are not geared toward increasing the efficiency of the existing socio-technical systems – hence further increasing global energy demand. Sheer number of users and devices and the AI revolution call for making energy efficiency GHG emissions a design element in digital techs.

The energy efficiencies of computers, Internet and deep neural network-based AI applications have reached fundamental limits, but overall computing performance and usage increases unabated.

At present, the energy efficiency of silicon-based computing is at least an estimated four to five orders of magnitude lower than human brains, which highlights the potential energy impact of AI replacing or complementing human cognitive tasks in the world economy.

The most likely result of these trends will be accelerated, increased energy demand for the Internet and AI in the coming decades, unless sufficiency considerations fundamentally change the current direction.

Environmental policy makers should consider explicitly including AI technology trends and scenarios in their decision-making.

Response strategies and design standards for AI and related digital technologies and platforms are needed which will also be important business opportunities.

[1] Roehrl, R. (2019). Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system. SLP/TFM research paper, December 2019

[2] Andrae, A., (2019). Drawing the fresco of electricity use of information technology in 2030 – Part II. Preprint Feb. 2019. Doi:10.13140/RG.2.2.31813.91361.

Solar Radiation Modification and its implications for the Sustainable Development Goals

Nicholas Harrison, Carnegie Climate Governance initiative (C2G)

Abstract

While awareness of the global climate emergency is growing, a persistent gap remains between international commitments and pathways to the 1.5–2°C goal of the Paris Agreement. Climate change impacts and responses are closely linked to sustainable development and in addition to a primary focus on emissions reductions, carbon dioxide removal and adaptation, new technologies are being explored to artificially cool the planet through solar radiation modification (SRM). SRM faces multiple uncertainties and knowledge gaps with potentially serious implications for delivery of the SDGs. An overview of the state of SRM research and development, implications for the SDGs and the need to strengthen governance is presented together with policy recommendations for possible pathways to addressing knowledge and governance gaps in future.

Increasing awareness of the scale and urgency of the global climate emergency continues to keep the issue at the forefront of concerns facing policymakers, business leaders and citizens internationally (UN, 2021; WEF, 2021; UNDP, 2021). Climate change impacts and responses are closely linked to sustainable development and every bit of warming matters (IPCC, 2018). Recent UN figures suggest that despite current government commitments to reduce greenhouse gas emissions towards the Paris Agreement goal of 1.5–2°C, atmospheric concentrations continue to rise (UNEP, 2020; WMO, 2020). According to the Intergovernmental Panel on Climate Change (IPCC), even global warming of 1.5°C is not considered 'safe' and poses significant risks to natural and human systems compared to current levels of warming (IPCC, 2018, p447). To address these and other risks that would result from overshooting 1.5°C, in addition to the primary focus on accelerating existing climate response options (emissions reductions, carbon dioxide removal and adaptation) in ways compatible with sustainable development, additional technology innovations are being explored to artificially cool the planet through an approach referred to as solar radiation modification.

What is Solar Radiation Modification?

Solar radiation modification (SRM) seeks to deliberately change the albedo of the Earth system, reflecting solar radiation (sunlight) back into space or allowing more heat to escape from the atmosphere to reduce peak temperatures resulting from climate change (IPCC, 2018). SRM would not address the causes of climate change, so could not substitute emissions reductions or removals, but could potentially reduce the climate impacts of a temperature overshoot, alongside intense mitigation and adaptation efforts (IPCC, 2018).

Examples of proposed SRM techniques include artificial injection of stratospheric aerosols, marine cloud brightening, and land surface albedo modification (IPCC, 2018, p558). The most researched technique is stratospheric aerosol injection (SAI), which would involve the dispersal of aerosols in the stratosphere to reflect sunlight, imitating the global cooling observed following volcanic eruptions such as Mount Pinatubo in 1991 (Dutton and Christy, 1992). While the IPCC notes high scientific consensus that SAI has the potential to limit warming to below 1.5°C (IPCC, 2018, p350), it also observes that such techniques face large uncertainties, knowledge gaps and substantial risks as well as constraints to deployment related to governance[1], ethics, and sustainable development (IPCC, 2018, p12-13).

Research and development

The potential research and development (or not) of SRM raises many scientific questions as well as other cultural, ethical, religious, geopolitical and security issues, and further evidence across and between disciplines will be needed to effectively answer them. This has already been acknowledged in a number of intergovernmental processes, for example among Parties to the Convention on Biological Diversity (CBD,

[1] Governance in this context refers to: "*...the full range of means for deciding, managing, implementing and monitoring policies and measures [and] the contributions of various levels of government... the private sector, ...nongovernmental actors, and of civil society....*" (IPCC, 2018, p550).

2016) and the UN Environment Assembly (UNEA, 2019).

Various assessments addressing SRM have been undertaken by national (Royal Society, 2009; National Research Council, 2015; Florin et al., 2020), regional (Schäfer et al., 2015) and intergovernmental bodies (CBD, 2012; Williamson and Bodle, 2016; WMO, 2018; GESAMP, 2019). The IPCC has convened an expert meeting on the topic (IPCC, 2012), and addressed the approach in its latest assessment report (IPCC, 2014) and special report on 1.5°C (IPCC, 2018). At the request of governments, SRM will be further addressed in its next assessment report (AR6) to be published in 2021/22.

SRM related research has previously received public and private financial support in Australia, Canada, China, Japan, Norway, India, the UK, EU, and the US among others (Necheles, et al, 2019) and a number of outdoor experiments are currently planned or underway to develop understanding relevant for SAI (SCOPEX, 2021) and marine cloud brightening (BRF, 2018).

In 2019 a US Congress Bill approved funding for research into the effects and risks of some SRM techniques (Science, 2020) and in March 2021 the US National Academies of Sciences, Engineering, and Medicine published a report calling for the US to cautiously pursue SRM research to better understand options for responding to climate change risks, suggesting a five-year research funding programme of $100-200m (NASEM, 2021).

Implications for the Sustainable Development Goals (SDGs)

Limiting global warming to 1.5°C would make it markedly easier to achieve many aspects of sustainable development, with greater potential to eradicate poverty and reduce inequalities (IPCC, 2018, p447). However, if international mitigation action continues on its current path towards overshoot of 1.5°C (UNEP, 2020) then can and should additional approaches such as SRM be considered to help avoid the significant risks to natural and human systems that would ensue? Could SRM actually reduce climate risks? Or would the relative risks presented by SRM outweigh the potential benefits for sustainable development?

While the SRM research literature identifies some potential interactions and impacts, substantial uncertainties and knowledge gaps exist (IPCC, 2018; Honegger et al, 2021). The overall impact of SRM on the SDGs is highly uncertain and dependent on climate change mitigation pathways and governance. Some scenarios suggest SRM could potentially assist in the pursuit of several of the SDGs by limiting temperature rise, acceleration in atmospheric water cycles, and extreme weather events (IPCC, 2018; Honegger et al, 2021). However, by introducing additional complexity and potential for conflict in global governance, as well as altering planetary environments, SRM might also detract from the pursuit of SDGs and introduce novel risks (IPCC, 2018; Honegger et al, 2021).

The need to strengthen governance

A precautionary approach to governance considers the relative risk presented by additional approaches such as SRM alongside, and in the context of, the risks faced as a consequence of the scale and pace at which existing climate response options are implemented. Governance involves actors beyond government (IPCC, 2018, p550), and given the scale and long-term implications and impacts that SRM potentially represents, international cooperation will be a prerequisite for effective international consideration and governance.

SRM has been initially addressed in a number of intergovernmental fora and processes, including the Convention on Biological Diversity (CBD, 2010; 2016), the London Convention and Protocol (LC/LP, 2013), the Montreal Protocol (UNEP, 2018) and the UN Environment Assembly (UNEA, 2019), but currently no comprehensive international governance framework exists, substantial governance gaps remain, and unilateral action is potentially becoming a serious SRM governance issue (IPCC, 2018, page 347).

While many constellations of intergovernmental and other organisations and processes exist, as the world's only truly universal global organisation, the United Nations is the foremost forum to address issues relating to sustainable development, peace and security that transcend national boundaries and cannot be resolved by any one country acting alone. While many parts of the UN system have important and influential roles to play that are relevant to the consideration and governance of SRM, as its main deliberative, policymaking, and representative organ, the UN General Assembly (UNGA) will have a key role.

Policy recommendations

Reflecting on the current international response to climate risk and new technologies, the following recommendations present possible routes to address knowledge and governance gaps around SRM and its implications for the SDGs:

1. *Catalyse international conversations to raise awareness and understanding about the potential risks, benefits and governance challenges* around different climate response options and whether or not SRM could or should be part of a global response to manage climate risks in the overall context of sustainable development.
2. *Consider whether and how to address governance gaps around SRM* including, *inter alia:*
    a) What governance framework(s) would allow coherent management of climate risks among the different climate response options available, including emission reductions; carbon dioxide removal, adaptation and potentially SRM, in the overall context of sustainable development.
    b) Whether and how to research SRM responsibly in the overall context of sustainable development.
3. *Consider whether and how to address knowledge gaps around SRM* including, *inter alia:*
    a) Whether and how to initiate the considerable research and policy work needed to understand how SRM functions, its impacts and how it could be governed, which would be needed before the international community could be clear if SRM is even a viable option.
    b) Whether and how to catalyse transdisciplinary and geographically diverse research on the interconnections between SRM and delivery of sustainable development.
    c) Whether and how to catalyse comprehensive quantitative analysis of potential risks and benefits of SRM to avoid under- or over-estimating climate and sustainable development impacts.
    d) Whether and how to catalyse integrated policy impact assessments to understand potential policy designs for research, development or deployment of SRM, and what implications they would have for delivery of the SDGs.
4. *Catalyse inclusive initial consideration by UNGA of how SRM should be addressed and governed* – given that it is the main deliberative, policymaking, and representative organ of the world's only truly universal global organization.

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Biomimicry to tackle air pollution in urban areas

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Key messages

Current urban areas are characterized by high levels of air pollution which remains a transboundary environmental problem, causing severe health issues and negatively affecting the environment.

Biomimicry provides a system-wide solution to urban air pollution by tackling the problem and aiding its prevention. It is a cost-effective solution which can be applied in many contexts, including in both developed and developing countries, at a variety of scales and can be implemented by different actors (through either top-down or bottom-up initiatives). Additionally, it produces secondary benefits that address other urban issues.

Currently, the identified barriers and challenges to the implementation of biomimicry in urban areas are socio-economic, environmental infrastructure and governance related.

In order to overcome these barriers and challenges, the collaboration of a variety of actors is key to implementing biomimicry in urban areas to tackle air pollution. The presented scenarios provide different pathways to make the concept of biomimicry more mainstream in education, investment and policymaking.

Introduction

"Biomimicry is the art and science of people emulating the best biological phenomena and strategies found in nature, by providing solutions with positive externalities, which will create conditions conducive for human wellbeing and biodiversity on Earth (Authors, 2020)."

Air pollution has become a global health emergency, particularly in urban areas, and is increasingly contributing to environmental degradation, which is causing a rift in the human-nature relationship.[1] Air pollution is responsible for 7 million premature deaths annually worldwide[1], as well as affecting the environment, for example in the form of acid rain and biodiversity loss.[2] It is an issue that affects everyone from low- to high-income countries, yet disproportionately affects the poor.[3]

As human activities are major sources of pollution, cities especially have become hotspots for outdoor air pollution. By 2050, it is expected that two-thirds of the world's population will be living in urban areas, making air pollution a top priority.[4]

The current measures in place to tackle air pollution are small-scale and not delivering the desired results. Biomimicry offers a system-wide solution to urban air pollution by providing innovative and sustainable solutions based on the regenerative capability of ecosystems. [5] It is a cost-effective solution, using both low and high technology, which can be applied in many contexts, such as in developed and developing countries. Biomimicry can be implemented at a variety of scales within a city, through the collaboration of several actors using top-down or bottom-up approaches. Apart from tackling air pollution, biomimicry reduces resource use and stimulates urban biodiversity.

This science-policy brief explores the most important barriers and challenges to the implementation of biomimicry in urban areas. Furthermore, it will present an overview of future scenarios for the adoption of biomimicry to improve air quality in urban areas.

Current State of Biomimicry

The key approach to implementing biomimicry is adherence to the Life's Principles: adapt to changing conditions; be locally attuned and responsive; use life-friendly chemistry; be energy and material efficient; integrate development with growth; and evolve to survive. Biomimicry is about imitating natural forms, processes, and ecosystems. Accordingly, the approach to measuring the effectiveness of urban biomimicry is through the Ecological Performance Standards (EPS), that relates the services of a building or infrastructure to ecosystem services of the surrounding natural area. Regarding forms, the Eastgate Centre in Harare, Zimbabwe, mimics the ventilation structures of termite mounds thereby decreasing indoor air pollution and carbon dioxide (CO_2) missions from ventilation. Thus, energy use was lowered by 90% compared to same-sized traditional buildings and therefore rent for tenants could be decreased by 20%.[5] Finalists in the Biomimicry Institute's design challenge mimicked the electrostatic properties of spider webs to capture harmful particulate matter in air filters, thereby improving health of rickshaw drivers in India.[6] The traditional concrete brick is the most used construction material in the world but produces large volumes of CO_2 and releases black coal into the air, which has been linked to respiratory health issues. Biomimetic bricks have been modeled after the way coral converts CO_2 to calcium carbonate, making it a carbon and black coal neutral process.[7] Another process imitation is Ant Colony Optimization (ACO), which uses algorithms based on trail pheromone communication between ants to optimize urban traffic flows and bike-sharing systems to decrease air pollution from congestion.[8] However, there are few applications of system-level biomimicry to tackle urban air pollution. It is essential for urban sustainability that solutions are implemented holistically to make a system and its individual parts sustainable.[9] Therefore, we investigate the barriers and challenges to the system-wide implementation of biomimicry in urban areas to tackle air pollution.

Barriers and Challenges

Socioeconomic

Implementing biomimicry in urban areas to tackle air pollution is a highly technical endeavor. In order to implement biomimicry solutions in the urban context to combat air pollution, multiple sectors will need to interact. Biologists are needed to understand functions in nature, engineers are required to adapt these into technology, and government or private sector involvement is needed to implement the solutions into the urban landscape. Collaboration between these different actors requires a common language to communicate properly but such a language is non-existent. This can partially be attributed to the fact that biomimicry education generally is lacking. There are also relatively few professionals trained in the field of biomimicry, especially in the specific context of tackling tackle urban air pollution.

Apart from the need for funding education in biomimicry, there is need for investment in biomimicry. However, biomimicry as a building design is hindered by a lack of awareness of bio-inspired infrastructure on the part of urban planners. Additionally, risk-averse investors are hesitant to invest in novel designs[10], and the construction industry instead uses traditional building methods to deliver projects quickly and cheaply. In these circles, there is a perception that biomimicry is more expensive than conventional building designs, but it is more cost-effective in the long-term through decreased maintenance costs and energy use.[11] Currently, biomimicry lacks a common language for interdisciplinary collaboration and lacks metrics to help convince urban planners, investors and the construction industry to implement biomimicry.

Environmental - Infrastructure

The biggest challenge to the implementation of biomimicry in urban areas is changing the mentality in urban planning and the construction industry. Existing buildings and infrastructure have not been designed for adaptability to rapidly changing environmental conditions. So far, urban planners have used narrow approaches to urban design and neglected the impacts of urban design, including the formation of heat-island-effects and poor air-flow circulation, thus stimulating air pollution. Cities lack the environmental infrastructure to measure air pollution and filter harmful pollutants. Hence, urban planners do not possess comprehensive and real-time data on air pollution in order to prioritize areas for the implementation of biomimicry. Moreover, buildings have not been designed multi-functionally according to the principle of evolvability. Consequently, empty buildings that are designed for a single purpose cannot be used or are taken down entirely, with the building materials going to waste, increasing the demand for new building materials that increase air pollution. Thus, siloed and short-term thinking in urban design and construction prevent the implementation of biomimicry.

Governance

The current regulation in place forms various barriers to the implementation of biomimicry and tackling air pollution. Firstly, current sustainable certification schemes, such as the Leadership in Energy and Environment Design (LEED) for buildings limit the development of innovative architectural designs.[12] Current certification often leads to copying past mistakes, but a trial-and-error process is essential for innovation in green architecture. Because of its strict requirements, many biomimicry projects cannot apply for governmental funding. Another challenge to the implementation of biomimicry within buildings is the current distribution of responsibility in urban areas. Current regulation disincentivizes long-term ownership of buildings, thereby discouraging investment in sustainable building designs that are cost-effective in the long-term. This also relates to the absence of regulation for the negative externalities of buildings. Thus, building developers are not stimulated to improve surrounding air quality. Biomimetic buildings provide ecosystem services beyond what sustainable certification schemes measure, meaning their positive impacts remain undervalued. Furthermore, many countries lack regulations regarding air quality and have limited institutional capacity to implement air quality management. Often, there are no specialized agencies for air quality, and urban planners lack clear guidelines on how air pollution should be monitored. If the current regulation remains unchanged, biomimicry will not reach the development stage to tackle air pollution.

Scenarios and Recommendations

Based on the expert interviews and literature review, four future scenarios have been developed, which explore the steps needed to implement biomimicry. The four scenarios provide a different pathway, all of which are viable and neutral. None of these scenarios are ranked in order and one is not preferred over the other.

Two main driving forces have been identified. The first is ‘future focus’ which explores how biomimicry will be implemented in cities to reduce air pollution. The second is 'implementation approach’, which presents the different types of projects that will be implemented.

The four scenarios are ‘Technology Reigns’, ‘The More (Biomimicry) the Merrier’, ‘The Green Revolution’, and ‘Nurture the Nook'. These four scenarios not only demonstrate the potential of biomimicry to reduce air pollution in urban cities but also delve into biomimicry as a method to harmonize the social-ecological system interactions and achieve the United Nations’ Sustainable Development Goals.

Scenario 1: Technology Reigns

In this scenario air pollution in the urban setting is tackled through an emphasis on the functionality of biomimicry and an integrated city approach. Biomimicry remains largely invisible throughout the city’s infrastructure but, due to its highly technical nature, significantly reduces air pollution. Implementing biomimicry in an integrated city approach is a challenging endeavor and requires large structural changes. Much of the funding comes from the public domain as the municipalities ensure a system-wide approach to implementing biomimicry across the city. These public funds also contribute to biomimicry education in universities where technical courses are taught across the sciences. Besides this, technical biomimicry professionals are spread across different departments and scales in the city working to ensure a unified approach in all city matters.

Scenario 2: The More (Biomimicry) the Merrier

In this scenario, there is an emphasis on the functionality of biomimicry, through a project-based approach, to tackle air pollution. Once more, biomimicry remains largely invisible throughout the city’s infrastructure due to its highly technical nature. However, in this scenario the biomimetic technologies are integrated into publicized public buildings such as city halls, museums or iconic landmarks and private projects and residences. These projects serve to exemplify the potential of biomimicry by illustrating the innovation of this solution. As public examples of the biomimicry technology these buildings are produced to the highest standards and specifications in every aspect within the building. The total effect on air pollution reduction depends on the number of projects instigated in the city. The ease of implementing these projects is far higher than a system-wide approach. Funding largely originates from private sources such as advocates and technical biomimicry companies. Similarly, biomimicry experts are concentrated in specialized departments and companies.

Scenario 3: The Green Revolution

In this scenario, the implementation of biomimicry is focused on the aesthetics and an integrated city approach, therefore the use of biomimicry is visible throughout the city. It is an inclusive approach where citizens with and without a background in biomimicry feel connected to nature as it is visible to all. At a university level, biomimicry programs are included in all departments. Implementing biomimicry on such a large scale will be a challenging endeavor. However, in this scenario both high- and low-tech solutions can be incorporated which lowers the barrier. Altogether, biomimicry will radically alter the face of the city. This involves the collaboration between biomimicry experts from both social science and technical backgrounds, city planners, and municipalities, who aim to integrate the visibly pleasing technology using a system-wide approach, greatly reducing air pollution. Funding would come primarily from the public domain.

Scenario 4: Nurture the Nook

In this scenario, biomimicry is implemented using an aesthetic project-based approach. A lot of time is spent on implementing low-tech biomimicry, by experts concentrated in specialized departments, that is visible throughout the area. Overall, a reduction in air pollution is dependent on the number of biomimicry projects within the city. The funding for these separate projects comes mainly from private enterprises such as architecture bureaus and consultancies, and the ease of implementing biomimicry is higher due to the focus on separate projects with low-tech. In this scenario, biomimicry would be inclusive for all citizens but also primarily exist in specific university departments.

Key Areas for the Future

These scenarios present four neutral pathways to implement biomimicry to combat air pollution in urban areas. The chosen scenario will depend on the context of the urban area and their specific goals. Regardless of the chosen scenario, the UN can support the implementation of biomimicry in urban areas through these recommendations below. However, local municipalities and nation states can implement these recommendations as well.

1. Stimulate interdisciplinary collaboration between professionals, such as engineers and biologists, and between a variety of urban actors including communities, private enterprises and government
2. Make funding available for integrated and individual biomimicry projects within cities
3. Make biomimicry more visible, physically in cities and theoretically in education
4. Provide guidance on how to make regulations more supportive to biomimicry innovation
5. Produce flexible certification schemes that stimulate innovation in the field of biomimicry

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Robotics for monitoring marine ecosystems

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Key messages

The use of underwater robotics can increase monitoring capacity of marine ecosystems more effectively, efficiently, and safely but there is a need for more support and accessibility.

Governments and international bodies of authority need to manage the deployment of underwater robotics through international agreements, regulations, and enforcement.

Data transparency is extremely important in the success of underwater robotics to ensure that no country is left behind

Interdisciplinary collaboration and multi-stakeholder involvement are required to support relevant developments and innovation of underwater robotics as a tool for achieving SDG 14 targets

Introduction

The oceans and the diversity of life within it are essential for climate regulation, food provision, and human health.[1] This makes marine conservation and ocean governance of the utmost importance for reaching SDG 14 “Life Below Water”. However, rapid global environmental change means that the oceans are facing increasing anthropogenic pressures, causing marine ecosystems* to degrade at alarming rates.[1,2] This has led the UN to proclaim a Decade of Ocean Science for Sustainable Development from 2021 to 2030, to “develop scientific knowledge, build infrastructure and foster relationships for a sustainable and healthy ocean”.[3] At the core of this is an increased need for ocean monitoring to meet societal needs and achieve effective marine conservation and ocean governance.[4,5] Currently, there are significant spatial and temporal gaps that exist when it comes to monitoring marine ecosystems around the world.[6] An emerging technology that can address these monitoring gaps is robotics. This policy brief will provide insights into the role of robotics in marine conservation and the enabling conditions needed to make this an effective emerging technology for monitoring marine ecosystems at a larger scale.[7]

What is robotics?

Robotics deals with the study and application of machines that can replace humans in carrying out tasks.[8] This policy brief will focus on the application of Underwater Robotics (UR) used specifically for monitoring purposes. These include Autonomous Underwater Vehicles (AUVs), Remotely Operated Underwater Vehicles (ROVs) and soft robotics. AUVs are

marine robots that are fully autonomous and capable of measuring various oceanographic parameters under the control of on-board computers.[9] ROVs are subsea* robots that can explore the deep seabed using a tether, video camera and lights.[10] Soft robotics is an emerging technology based on the biomimicry*of marine species.[11] These robots can look, feel, and move like biological marine animals.[12] There is immense potential for marine robotics to continue developing as a key technology that enables the implementation of challenging missions in marine areas.[13] The proposed applications of robotics are monitoring: 1) invasive species*, 2) biotic and abiotic factors*, 3) trends of human impact on marine ecosystems, 4) progress of conservation goals and targets, including SDG 14.

Potential benefits

Increasing monitoring capacity

Accessibility and efficiency

By using UR for monitoring marine ecosystems, interested stakeholders can further access, explore and monitor the seas. This is because using UR allows researchers to access desired locations despite weather conditions or time of day.[14, 15, 16, 17, 18, 19] It also allows for continuous and detailed data collection over larger areas.[18, 19] For example, robot fish can collect oceanographic data with unrivaled coverage.[15, 20] With the continuous flow of data from UR monitoring projects, scientists can better understand marine ecosystems and assess the effects of human activity on marine ecosystems.[15, 21]

Human Safety

UR can improve the safety of personnel involved in monitoring marine ecosystems, as robotics can conduct initial assessments of the area before divers are sent on a mission.[22] UR could also prove resistant to external forces such as a global pandemic (COVID-19) as it is possible to continue monitoring marine ecosystems with robots.[23] With UR, the worst-case scenario is that the robot gets lost or is irreversibly damaged.[24] However, this is preferable to people currently entering dangerous situations to monitor marine ecosystems.[25] Thus, UR for monitoring is much safer than having to send divers to conduct surveys.

Compared to traditional monitoring methods

Increased accuracy

UR can increase the accuracy of data collection compared to traditional monitoring methods. These include tagging*, diver surveys* and transect surveys*. Human divers and different boat captains traditionally involved in monitoring missions mean there may be inconsistencies in the trajectory of transects. Conversely, autonomous robots are programmed with the same trajectory each time, increasing the consistency of the collected data.[15, 19] There may also be biases in the way human divers collect data, for example, if there are distractions underwater or if the diver must go back to the surface. This is not the case for robotics as robots are programmed for consistent data collection and can stay underwater longer than human divers.[26]

Less intrusive

Traditional monitoring methods are often intrusive and labor-intensive.[25, 27, 28, 29] This may intimidate and distress marine life, causing them to swim away or hide. With soft robotics, monitoring can be less intrusive to marine life as they can get closer to marine life than divers.[26,30] UR can monitor and survey multiple aspects at the same time, meaning only one robot is needed to carry out the tasks of multiple people. This limits human presence and its negative impacts such as re-suspending sediments and reef damage to sensitive flora and fauna.[31, 32] This in turn can limit the stress experienced by marine life. [31, 32]

Potential risks

Risks to marine conservation

Intrusion into marine ecosystems

Despite the potential of UR to be less intrusive to marine life compared to traditional methods, there remains a risk of negatively impacting marine life. Firstly, by introducing UR into marine ecosystems, there is a chance that this will impact marine interactions and alter behavior.[33,24] This is particularly true if UR is not maneuvered with caution.[27] Additionally, this could lead to physical damage to the environment.[27, 17] This points to the need for UR guidelines to minimize any potential impacts.[24] It also highlights the importance of working with robotic technologies that are less intrusive in marine ecosystems, such as soft robots.[34, 26]

Marine pollution

There may also be a "hidden cost for the environment."[33] If the robots break down and are not recovered, they remain in the marine ecosystem as litter.[33] UR therefore come with the risk of marine pollution.[33,25] This risk is further enhanced if the robotic system breaks and causes leakage.[33,26,35,24] Without proper guidelines to ensure the minimization of this risk, this could have negative implications for marine conservation.

Noise pollution

In addition to marine pollution, UR can introduce noise pollution that may negatively impact marine life.[18,33,35,29,24] Noise pollution from other sources can negatively affect marine life, causing population-wide and ecosystem-wide changes.[36,37] UR may therefore also present this potential risk.[38] For example, depending on the frequency level used by UR, it is possible they interfere with communication amongst marine life.[29] A potential solution could be the use of soft robotics as they are designed to monitor marine ecosystems silently. However, further research is needed to fully understand and minimize the potential impacts of noise pollution from UR.[29, 33]

Invasive species

UR can provide a potential pathway for the transmission of invasive species.[39] UR, like micro ROVs, can be transported among ecosystems in different regions with relative ease, meaning they can act as a vector for invasive species.[39] Although introductions of marine invasive species have not yet been directly attributed to UR, there are other examples of scientific research gear acting as vectors for invasive species.[39,40] Additionally, invasive species have been found to raft on marine litter, which may present a risk for broken down UR.[41] Given the significant threat invasive species pose to marine ecosystems, it is imperative for UR users to follow guidelines that reduce the risk of invasive species introduction.[39]

Monitoring used for exploitative purposes

Finally, while UR may directly impact marine ecosystems, they may also pose indirect risks to marine conservation. This is because there is a “competition between nature preservation and economic benefits,”[16] which means that UR could be used for purposes that have adverse effects on marine ecosystems. For example, rather than monitoring for conservation purposes, UR could be used for deep sea mining*.[16,19,29,42]

Societal risks

Security

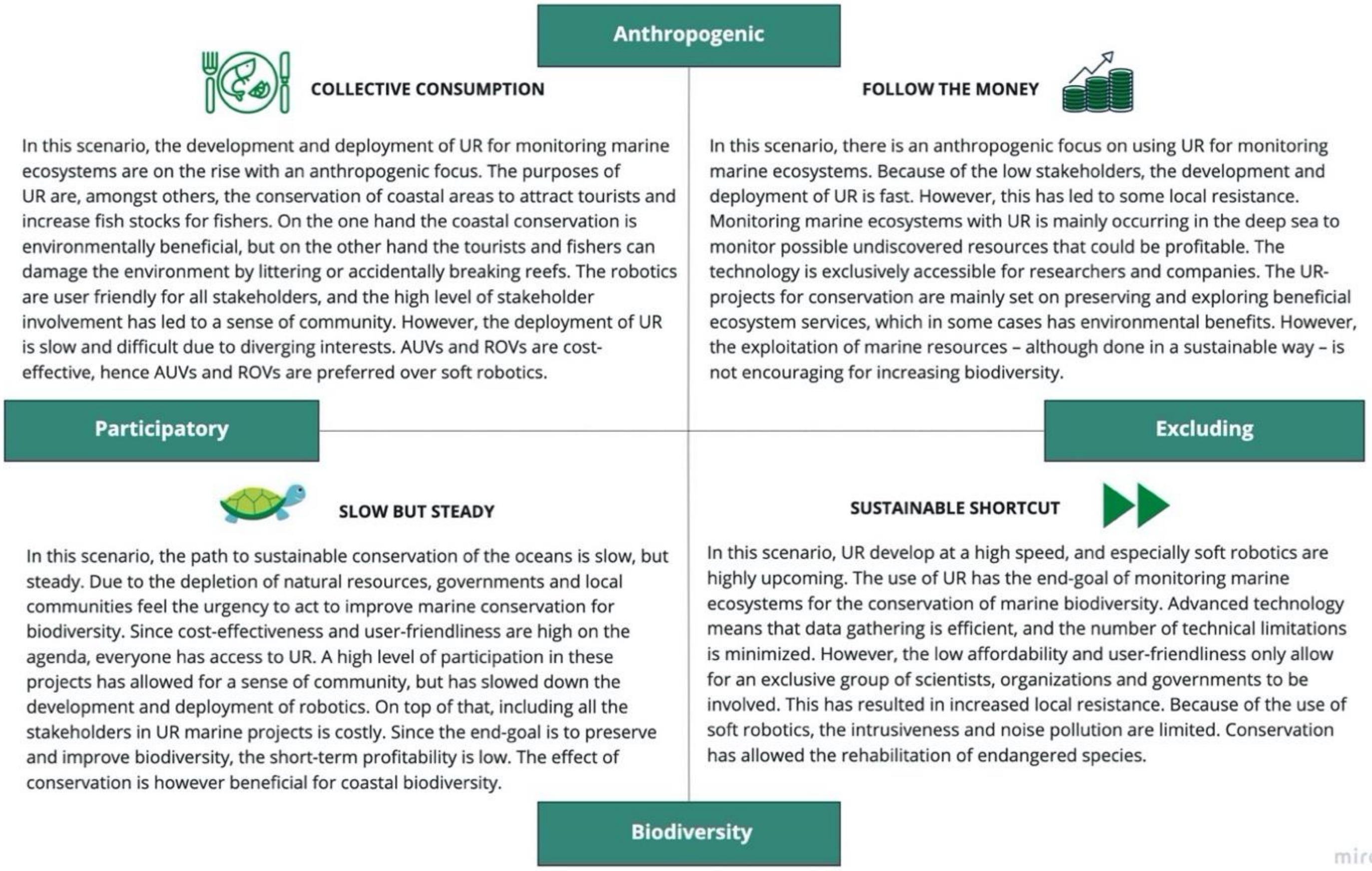
UR can also present potential security risks to coastal states.[43] Firstly, UR are at risk of cyberattacks.[43,23] For example, a cyberattack at the firmware/OS level could allow remote control over robotics, whereas an attack at the hardware level could allow robotics to be disabled.[44] Additionally, there exists the possibility that they will be used to further geopolitical agendas* of states at the detriment of others.[45,46] For example, it is possible for UR to be armed.[47] In order to deal with this risk, it is essential to align the laws of different nations with the ones of international entities.[46] Furthermore, what on the surface appears to be monitoring for the purposes of conservation can be part of military research. This could prejudice the security interest of states, and it is therefore an “underlying fear” of coastal countries.[43] Similarly, monitoring could also threaten the economic security of coastal states if the information is used by corporations or other countries to exploit its natural resources.[43] Coastal states, especially within their twelve nautical mile limit, are therefore “very concerned with [their] security”.[43]

Stakeholder analysis

Due to the complex nature of stakeholders in terms of the multiple roles they can play, a traditional top-down approach* is not suitable for creating the enabling conditions needed to make UR an effective emerging technology for monitoring marine ecosystems at a larger scale.[48] In the case of UR monitoring of marine ecosystems, thirteen stakeholders with varying interests have been identified. They exist of environmental activists, funding companies, governments, Independent Scientific Bodies, Indigenous People and Local Communities (IPLC), International Body of Authority (IBA), local fishers, military organizations, Non-Governmental Organizations (NGOs), private companies, scuba diving industry, tourism industry and universities. A multi-stakeholder collaboration is desired to ensure inclusion and to prevent resistance against the deployment of UR. This highlights the need to explore different scenarios of the deployment of UR, in order to fully understand the role and influence of different stakeholders in each of the plausible futures.

Scenarios of Robotics for Marine Ecosystem Conservation

The following four scenarios explore the potentials of the deployment of UR for monitoring marine ecosystems. At the basis of these scenarios are the main drivers ‘future focus’, which entails the focus on the way in which robotics for monitoring marine ecosystems should be applied, and ‘user involvement’, that describes the degree to which different actors are involved in the decision-making process of projects that use robotics for monitoring marine ecosystems. These four scenarios are 1) Collective Consumption, 2) Follow the Money, 3) Slow but Steady and 4) Sustainable Shortcut. In each of these scenarios different stakeholders play a key role in the development and deployment of UR. Moreover, every scenario comes with its own specific benefits and risks. This means that each scenario needs its own sets of regulations.



Key Enabling Conditions

The specific enabling conditions required for making UR an effective emerging technology at a larger scale depend on the specific scenario chosen by a policy maker. However, regardless of the chosen scenario, there are some key recommendations that apply in every case and thus require serious consideration. These are based on all the risks and benefits described in this policy brief, and on the general recommendations from the expert interviewees. The key recommendations of this policy brief can be found in the table below:

Key Recommendations

- Developing underwater robotics with monitoring capabilities as a tool for achieving **conservation goals** rather than a goal within itself.
- An **interdisciplinary approach** to the development and deployment of underwater robotics for monitoring marine ecosystems is required to minimize risks.
- Underwater robotics **regulations made by intergovernmental bodies** are necessary to control and minimize the risks involved.
- Ensuring **data ownership of regional powers** to monitor the use of underwater robotics within their jurisdiction in order to minimise conflict and risk.
- **Independent scientific body*** required to monitor underwater robotics research in marine ecosystems to ensure transparency and a high level of trust.
- The **enforcement of clear guidelines** for all stakeholders using underwater robotics in marine ecosystems is needed to ensure the safety of marine life and environments.
- **More funding opportunities** for the development of UR is required for research, to overcome current technical limitations. In order to ensure that no country gets left behind, countries should consider **multilateral funds** and mechanisms for technology transfer.

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Power digital IT technology to realize distributed power

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Energy-prosumer vision

With distributed power, the power source is spread widely and split into many units. Ideally, in distributed power generation not only businesses, such as large corporations, factories, and small and medium-sized enterprises, but also common households directly produce power through solar power generation (at small scales of around 1 to 2 kW). It leads to "energy-prosumers" where who uses electricity is also a producer and seller of electricity.

Technologies needed

Of course, for such vision to become reality, a system of emerging technologies is required – primarily electric intelligent devices such as the following:

- *Intelligent Power Metering System*: This refers to a power service infrastructure based on two-way communication and information exchange between electricity consumers and power companies.
- *Demand response (DR):* This refers to the base technology for providing services that lead electricity consumers to consumption patterns that reduce electricity use by reacting to incentives.
- *Energy storage system (ESS) and energy management system (EMS):* These are energy management and storage technologies to reduce energy use and increase overall energy efficiency.

Among them, ESS in particular helps storing the generated power of renewable energy generation sources that are intermittently generated in connection with the power system, and EMS is a device that balances the energy supply and demand of the entire energy system in a unit area.

However, in order to implement the full energy-prosumer concept, these technologies are not enough. We need new technologies which is more improved than the above technologies, and to introduce real life, technologies to support them and to create various environments are also required.

Low cost of renewable energy: The cost of renewable energy, which produces electricity through eco-friendly energy sources such as solar and wind power, has fallen a lot through active technology development and dissemination policies and mass production in many countries. Some energy sources have also achieved grid-parity. Still, in many countries, it is not easy for ordinary households to generate electricity from renewable energy sources and further sell it. In order to realize a true distributed power supply and to realize an energy prosumer, technologies related to sustainable renewable energy cost reduction must be promoted.

Grid connection and stabilization technology of small power supply: As mentioned above, in order for all households to introduce small-scale renewable energy facilities to produce and sell electricity, even small-sized renewable energy sources, such as 1-2 kW, must be easily connected to the power system. To do this, it is necessary to expand the width of the power facility capacity that the power system network converges, and above all, a technology that can stabilize the system so as not to cause confusion while connecting numerous distributed power sources to the system is needed.

Real-time power monitoring technology: When all households produce and sell electricity, technology is needed to monitor how much electricity is produced in each household, what is the real-time output, and how much is sold, concretely quantified and monitored. When digitized information can be recognized with the eyes, all power producers will be incentivized for power generation.

So far, we have introduced the core technologies necessary to achieve a true distributed power supply and energy prosumer.

SDG impacts

What we want to achieve by combining the above technologies can be summarized as improving the quality of life and alleviating poverty through the realization of a decentralized power source, realizing gender equality through decentralized power, and improving human rights. Here's a more detailed account of how the above technologies will affect the achievement of SDG.

① *Eradication of poverty & ending hunger:* Distributed power through renewable energy itself becomes a stable source of income, and when renewable energy generation facilities can be introduced with small capital enough to be easily installed by anyone, it will greatly contribute to democratization of the economy. .

② *Quality education:* Inequality in educational opportunities arises from the extreme gap between the rich and the poor. If poverty eradication is achieved, quality educational opportunities can also be given to many.

③ *Gender equality & easing inequality:* Small-scale renewable energy generation and energy prosumers do not distinguish between high and low status, gender, and age.

④ *Clean energy & climate change:* Renewable energy, which is a source of income, is basically clean energy that does not use fossil fuels and contributes to climate change mitigation by reducing greenhouse gases.

⑤ *Industrial innovation and social infrastructure:* The decentralized use of renewable energy will establish a stable and solid socio-economic foundation and have a positive impact on industrial innovation through advanced digitalization technology.

⑥ *Sustainable cities and communities:* Renewable energy facilities can be installed on a small scale in each household, or they can be jointly invested and operated by a union within the community. It can develop into a resilient community that embraces more people and, in turn, into a city.

⑦ R*esponsible consumption and production:* Properly producing and consuming renewable energy is itself a responsible action for climate change and the planet and contributes to the sustainable development of mankind.

⑧ *Sustainable protection of terrestrial ecosystems, prevention of desertification, etc.:* When the distributed power of renewable energy is expanded, no more fossil fuels are required, which prevents desertification and ensures continuous protection of terrestrial ecosystems.

⑨ *Peace, justice and institutions:* The energy structure that mankind mainly operated after the Industrial Revolution was through large-scale power generation facilities by large-scale capital. Even the fuel was based on fossil fuels such as coal and oil, which are responsible for climate change. Large-scale facilities are invested in large-scale capital, which basically disables everyone's participation and increases barriers to entry, preventing accessibility. Therefore, the power to produce energy was concentrated in some, and most of the people belonged to the side that unilaterally consumed the energy necessary for survival.

Conclusion

In this process, progress on innovation in the way energy is produced and the supply structure has been difficult to achieve. Distributed power through renewable energy can revolutionize this structure. Renewable energy production facilities, which are spread out thin and wide, can disperse capital and power concentrated in one place. The general public can also participate in the production of human blood-like energy and, in the process, can pursue continuous change in a way that is more environmentally beneficial to the planet.

The meaning of “distributed power by renewable energy” means that the majority of humans become active energy agenst rather than merely passive energy objects, and technologies for this will contribute to SDG.

5G in irrigation: exploring pathways for implementation

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Key messages

5G for smart irrigation can be used in monitoring, decision-making and application (e.g., in robotics) in irrigation, making water use more effective, efficient, and sustainable. However, barriers related to data and network governance, inclusive access and societal adoption need to be tackled to mainstream this emergent technology for smart irrigation.

Future scenarios show a risk of growing inequalities and of concentration of power and knowledge that could leave a big share of the population behind.

Close collaboration between the public and private sector in terms of network, data governance and inclusive access is required to support further implementation of 5G in smart irrigation as a tool for achieving SDG 6

Introduction

Fresh water is becoming increasingly scarce.[1] The agricultural sector is both a cause and a victim of this issue[2], as it uses about 70% of all freshwater resources.[3] This is an excessive usage rate that is degrading land and draining water reservoirs.[2] Climate change has increased the urgency of finding solutions to reduce water use in the agricultural sector and several highly promising solutions have emerged. **5G***, the newest generation of network technologies, has emerged as the application that will 'revolutionize' water use in agriculture. Using this emerging technology, available water and water stress can be measured accurately and precisely. While this was – to some extent – also possible with previous networking technologies, 5G will make connectivity between devices a lot faster, while facilitating more devices to connect to a single cell tower. This last element is essential, as digitalization in agriculture is on the rise[4], increasing the demand for a network that supports more devices and a larger data flow, and connects rural areas.[5] Moreover, the process of irrigation can be automized using 5G-enabled autonomous robotics, making irrigation more efficient and effective. In pilot projects by Nokia, the application of 5G on smart irrigation has shown to reduce the amount of irrigation water by 30% on several farms.[6]

Current Debate

Field trials for 5G and smart irrigation have only just started.[7,8] The first trials related to **IoT***-enabled smart irrigation were promising – for example, a local peach farmer in a salinized region in Algeria has been able to increase revenues by 5% whilst decreasing water use by about 40%.[8] However, results of trials using 5G specifically are still in progress. Nevertheless, the technology has been described as a key enabler for IoT-based smart irrigation that will increase its capabilities, efficiency and make smart irrigation more accessible by combining **LoRa*** networks and 5G capabilities.[5,9]

Current debates mainly revolve around whether 5Gs implementation will contribute to widening or narrowing the divides between rural and urban areas or developing and developed countries. Initially 5G was "*designed with the goal of minimizing inequalities in physical access, in particular differences in access that arise as a consequence of the rural-urban divide*"[10], promising even that the share of the population that currently has no access to basic connectivity could

BOX 1: 5G NETWORK TECHNOLOGY

The newest generation of telecom networks, 5G is a technological breakthrough. 5G first accessed the markets in 2018[13] and will continue to expand, with currently 38 countries deploying and 129 countries looking for pathways to deployment.[14] 5G technology was initially developed to make **network slicing*** efficient.[13] Next to enabling network slicing and supporting tailored network use, the key characteristics of 5G are the extremely low **latency***, the ability of 5G to support up to a million devices per square kilometer and low power consumption.[15] These characteristics support 5G's three main use cases: massive machine to machine communications, ultra-reliable low latency communications and enhanced mobile broadband.[16] 5G will most likely co-exist with other network technologies, such as **Wi-Fi***, LoRa and **4G***, but is expected to take up a large market share in the near future.[9,17,18]

shrink by half.[11] Moreover, the economic and social benefits would be profound.[11]

However, delivering connectivity enhancements will come at a rather high cost, making it uncertain whether connectivity providers have sufficient incentive to cover most parts of the world with high-band access.[11] It is likely that late adopters will significantly lose out on social and economic opportunities.[10] Therefore, some argue that 5G is inherently non-inclusive, as 5G will *"speed the obsolescence of technology low-income people can afford"*.[12] Making the deployment of 5G fairer rather than faster could be a possible way to decrease growing inequalities.[12]

Challenges for Implementation

BOX 3: CONNECTING THE UNCONNECTED, 5G & LoRa

Another network technology that is currently being exploited in smart irrigation is LoRa.[9] LoRa is increasingly being applied to irrigation and precision agriculture, because of its long-range that allows wireless communication to secluded areas with no service.[9] However, LoRa is not capable of transmitting higher volumes of data. As digitalization in agriculture will continue to expand[23,24], and dataflows will increase as a consequence, 5G can make a large difference. "For IoT systems that require the transmission of large amounts of data, 5G would solve the problem of the limited amount of data that LoRa can transmit".[9] An interoperable use of LoRa and 5G hybrid wireless networks in the future could therefore be the future of connecting the unconnected.[9]

As trials mentioned above are set in mid- to highly developed countries, the question remains whether 5G could also contribute to irrigation practices in the developing world. This question is essential, especially because it is these developing countries that are already experiencing the highest numbers of water stress[19], often related to the contribution of their agricultural sector.[1] To answer this question, the main challenges to 5G's implementation were investigated. These include governance[20], access[21] and societal adoption challenges.[11,22] Related to governance, the main challenges that were identified are the development of international **standards***, ownership and accountability sharing between national governments and large (international) telecom operators, and the development of an effective data security framework. Accessibility is challenged by the **digital divide***, which also becomes apparent when looking at digitalization levels in agriculture, network coverage in rural areas and gender differences in ownership of and access to digital devices. The biggest challenges policy makers adopting 5G in smart irrigation are low levels of awareness related to 5G's benefits in irrigation, limited knowledge sharing and education, partly as a result of the lack of use-cases in irrigation, and a reluctance to work with 5G for various reasons.

BOX 2: APPLYING 5G IN SMART IRRIGATION – MONITORING, DECISION-MAKING AND APPLICATION

A highly promising application for 5G in smart irrigation would be the use of different **sensor nodes*** in the field, connected to the 5G network. These nodes monitor soil and crop conditions individually and transfer the data to the network in real-time. The data consequently arrives to the farmer in the blink of an eye, providing accurate information on what the specific water needs of a specific crop are at that precise moment. Experts argued that using 5G for monitoring and decision-making purposes, for example by using these nodes, is probably the most promising application in the developing world. This is because these products are relatively cheap and less complex to handle than other applications, such as 5G-enabled robotics. These nodes will prove to have a high impact, as it will improve farmer's decision-making on time, place and amount of water that is delivered. Although nodes exist for other network technologies, 5G will speed up their communication, allowing more data to be processed with increasing accuracy and supporting rural connectivity. Applying 5G to robotics could contribute to immaculately precise irrigation, which will save water compared to **sprinkler irrigation***, for example. However, as these robotics are - and will remain - expensive according to experts on smart agriculture, they remain inaccessible for a lot of (smallholder) farms.

Roadmap

In order to describe pathways for implementation of 5G and to anticipate their consequences, four scenarios were identified. These scenarios are exploratory, meaning that they entail a range of possible consequences of strategic decisions made by the industry, policy makers and consumers. Based on examination of these scenarios, different effects on accessibility and inclusiveness are identified. Policymakers can choose their preferred scenario and rollout 5G accordingly. In line with policymakers' needs and resulting actions, each scenario is equally likely to become a reality. Finally, a list of policy recommendations is provided per scenario, taking into account associated risks.

5G: Pathways for Implementation

The following four scenarios are neutral, meaning that one is not necessarily preferred over another. They are based on five main driving forces. The scenarios and identified driving forces are based on expert interviews and extensive literature review. The scenarios are based on two axes: the scale of impact on water scarcity and the scale of accessibility. The former explores the goal for implementing 5G in smart irrigation: reducing water use versus water use optimization. The latter explores for whom 5G will accessible: either for the few (elite) users or for society at large (for the many). The scenarios envision how and by whom 5G for smart irrigation may be implemented in ten to twenty years from now, describing specific risks and benefits of each pathway.

Scenario 1: Early Adopters

In this scenario, 5G largely remains exclusive, mainly available for 'early adopters' who can afford to use it without large scale funding. National governments have a limited role in the implementation of 5G and supporting the first use cases and innovations in smart irrigation. Use-cases are privately driven and focus on specific contexts. The ownership of the 5G spectrum is mostly privatized, meaning that it will be mainly large private agricultural businesses with sufficient resources developing their own 5G networks. The knowledge on 5G and its use-cases for smart irrigation are concentrated within these early adopters. Knowledge sharing largely occurs within these circles, as use-cases are limited and the business case for wider society, e.g. SMEs in agriculture, is not clear yet. Furthermore, the availability of the networks is expected to be limited to the privately developed networks, resulting in fragmented coverage. Requirements of use remain rather high: these early adopters have the right means and access - including financial means, electricity, digital literacy and access to the spectrum - in order to reap 5G's benefits. As a consequence, 5G-enabled smart irrigation remains rather exclusive, specifically focused on farmers already used to working in a high-tech context. Applications of 5G for smart irrigation are focused on automatization of the irrigation process to increase profitability of these early adopters. A major risk of this scenario is that current inequalities will increase: if only the early adopters profit from this new technology, the majority farmers, and especially smallholders, will be left behind. This risk is serious, because a relatively large share of farmers is in areas characterized by water scarcity. Benefits include higher yields for these adopters, most likely key players in agriculture in the developed world.

Scenario 2: Competitive Adoption

In this second scenario, 5G's availability is based on commercial criteria. The networks are privately owned, following auctioning of the spectrum by governments to private companies. Both individual farmers and large-scale exploitation use 5G in smart irrigation.

Moreover, there is general knowledge on 5G and its use-cases, but this is dependent on the application trend in the specific context. Knowledge is also commonly shared within farmers who can access 5G networks. These networks will be available depending on their applications, but as markets are usually larger in urban areas, not everyone will have access. Because of rapid developments and high investments from private entities, the technology will be more accessible in terms of coverage. In this scenario, smart irrigation becomes more inclusive, as user requirements, such as digital literacy and financial resources, are more likely to be met by farmers. However, as the spectrum is privatized, the entry fees remain significant. Applications of 5G are both used for monitoring and decision making and automation for smart irrigation as its main purpose is still to optimize the productivity. Therefore, 5G-enabled smart irrigation can be deployed in both high-tech farming practices and partly as well on farms using less complex technology.

The main risks are increases in water use as an unintended consequence and persisting inequalities. The main benefits are the higher accessibility of the technology and optimized crop production on a larger scale.

Scenario 3: Targeted Action

In this scenario, 5G is promoted as a key enabling technology by governments to limit water use in agriculture. The coverage of 5G networks is limited, as it is likely that the technology will be deployed in certain designated companies or regions. A mix of public- and public-private networks exists. 5G is mainly used to automize production processes, thereby reducing water use. This automatization and focus on the high-tech applications of 5G-enabled smart irrigation implies that the technology will remain exclusive to the companies or regions that have been designated by governments to make a change. The level of knowledge sharing is on the lower side, as knowledge remains in a closed bubble of actors, though some sharing might happen within a specific agricultural sector or region. Therefore, requirements of using 5G remain high. Farms in this scenario are deploying high-tech solutions and can be used by an informed public.

The risks of this scenario relate mainly to power and knowledge concentration in the hands of a few actors, namely the ones benefiting from 5G's uses. A big share of the population might be left behind as well. Benefits include a reduction of water-related costs, decreases in water scarcity on a local level and a relative ease to regulate.

Scenario 4: Access for All

In this scenario, the 5G network is accessible for most farmers – regardless of size or sector – as a result of government incentives to roll-out 5G through specific plans. A large effort in rolling out 5G is made by public entities to reduce water use as a result of current or foreseen water stress. In this scenario, the 5G network is accessible for most farmers – regardless of size or sector – because of government incentives to roll-out 5G through specific plans. The ownership is led by public entities, to control the increased data flows and to secure data storage and processing. The network has thus not been auctioned to private telecom operators. A full coverage of 5G networks is expected, making 5G accessible for application in remote areas. Levels of knowledge sharing are high, as governments try to increase digital literacy and skills, while at the same time decreasing the requirements of using 5G in smart irrigation. This results in accessibility of 5G in smart irrigation for anyone willing to adopt it. Applications of 5G depend on the context: in some contexts, robotics might be used to finetune water use in agriculture, while in other contexts – especially where farming practices are generally low-tech – 5G-enabled nodes are deployed to make better and more timely decisions on the amount and placement of irrigation. The risks of this scenario are two-fold. First, increased data flow can pose a threat to data security. Second, there could be a slow development of high-tech solutions. The main benefits are the fact that no one is left behind while limiting water use on a significant scale.

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Policy Recommendations

- National governments should develop a comprehensive roadmap for the implementation of 5G. This roadmap should consider the aforementioned implementation challenges.
- International standards for data security should be discussed and introduced by relevant/competent authorities.
- National bodies should create an enabling environment to develop use-cases of 5G in smart irrigation and use these projects to stimulate knowledge sharing among farmers and communities.
- National roadmaps are needed to introduce digital education in public schooling to reduce the digital divide.

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Ablative pyrolysis for sustainable energy production

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Abstract

Fast pyrolysis is a sustainable and clean method of energy production which has been made more accessible and efficient through ablative technologies and improved catalytic upgrading.

Ablative pyrolysis reactors can convert a wide variety of plant materials into bio-oils and biochar which can be used within the community for farming, cooking, or fuel, or it can be sold for a profit.

The use of mobile ablative pyrolysis units can provide economic and social empowerment to low-income communities and can improve the health and workload for women.

Further research is needed to overcome burdens from large initial financial investments and close research gaps that currently limit its practicality

Introduction

Pyrolysis* has been implemented globally for thousands of years to generate various incinerated materials such as char. As pyrolysis developed, fast* ablative pyrolysis is one type that has been explored for producing biofuels that can be refined to produce biodiesel.[1] Ablative pyrolysis* additionally demonstrates a clean way to decompose biomass, especially compared to incineration. Further uses include the production of biochar, which can improve garden or field crop yields, and can improve the retention of water within the soil.[2]

The novel technological upgrades focus on catalytic upgrades, ex-situ* and in-situ*. These innovations help to further speed up the chemical reactions that aid in the removal of oxygen that results in a higher quality product.[3]

Potential Ablative Advantages

- Mobile Unit Production
- Little need to grind materials, reducing costs significantly
- Modest transportation costs stemming from mobile units and light weight of bio-oil
- Large diversity in what can be utilized as biomaterials
- Large diversity in what can be produced – biochar, biogas, and bio-oil
- Efficient systems with bio-oil yields of up to 70%[4]
- Reduction in air pollution compared to burning biomass
- Reduced deforestation from providing alternate fuel sources for domestic use
- Resource sovereignty
- Reduce respiratory issues resultant from traditional cooking fuels
- Option to retrofit current oil refineries to refine pyrolysis produced bio-oil

SDG Connection

The introduction of ablative pyrolysis as a viable technology source would directly benefit work towards SDG 7 "Achieving Affordable and Clean Technology". Additionally, since ablative pyrolysis is a carbon-neutral producer of fuel, it would help replace other fuel productions contributing to climate change, working towards SDG 13 "Climate Action". The efficient use of biomass and feedstock as input materials for ablative pyrolysis reactors contributes to SDG 12 "Responsible Consumption and Production" by providing unused and surplus of biomass a purpose in producing clean energy sources.

Scientific Debates (Based on Expert Interviews)

Many researchers contend that ablative pyrolysis will advance sustainable development. Those that agree point to the high rates of heat transfer, making the process fast, cheap, and highly efficient. Another area is the complexity of the technology. Some feel that the simplicity of ablative technology warrants it for sustainable development, especially with the long historical presence of pyrolysis. Still, others contend that because of research gaps, ablative is far too sophisticated for conventional use. Thus, a few researchers commented that it should not be utilized or another pyrolysis method like fluidized beds should be developed instead.

Economically, due to the decreased need to grind biomaterial, and the lessened material costs for small, mobile units - ablative is potentially cheaper than other forms of pyrolysis. Yet, there was wide unanimity that, because of high start-up and material costs, ablative is difficult to implement without a significant investment.

The consensus is that more research must be spent on ablative pyrolysis to further improve it. As well, most researchers conclude that a huge advantage is that ablative pyrolysis is more easily transferred into cheap mobile units. However, few mobile units have ever been tested, splitting consensus on whether ablative should be utilized for sustainable advancement.

Sustainability Examinations

1. **Scalability**
2. **Accessibility for Low-Income Communities**
3. **Community Resilience**
4. **Women Inclusion**

Scalability: Mobile vs. Large Scale

A key feature of ablative pyrolysis is its ability to have a compact design, with the eventuality of the construction of mobile units. Preliminary work has shown that lab-scale units have bio-oil yield of 60% weight, but the added benefit that materials did not have to be ground before use.[5] Key applicability here is the notion of utilizing mobile units for local communities and in the field i.e., farm, forest, etc. Larger systems present significant problems for ablative pyrolysis. Maintaining high enough heat, pressure, and maximizing surface area exposure to ablation is difficult, so compared to other pyrolysis methods, ablative is difficult to scale up. Researchers contend that the focus should be on implementing mobile units, not only for increasing individual access, but also for simplifying the design.

Accessibility for Low-Income Communities

Economically, there are large start-up costs for implementing ablative reactors. However, if the initial costs are covered, ablative mobile units can be brought to places with little infrastructure and close to the biomass source. Thus, providing more access to the pyrolysis units and reducing operating costs to produce bio-oil. The cost of the unit can be offset through the sale of bio-oil and biochar directly and through the increased revenue from greater crop yields resulting from biochar use in soils. Pyrolysis units are already in use in developing areas, like the Ukraine,[6] but continued research is needed to reduce costs.

Community Resilience

There are difficulties in high costs and the lack of research in practical mobile units. However, interviewed scientists still promote the potential for ablative technology to empower small communities. In energy justice studies, provincial involvement and ownership of energy is a key aspect in respecting local institutions. Ablative mobile systems would require localized education, training, and direct contact with the energy source, fostering said engagement.[7] Moreover, opportunities arise for job creation and financial benefits from the use of local biomass, such as maintenance, feedstock collection, and transportation.[8] Finally, greater energy security is achieved by communities utilizing their own biomass, rather than relying on fluctuating fuel prices. In places where local biomass is burned, bio-oil provides a pollution free energy generation source.[9]

Women Inclusion and Justice

Ablative offers a unique opportunity to lessen the health burden and workload for women, who more often do domestic work like cooking and fuel collection. Three billion people globally cook with polluting sources like wood, coal, biomass, etc. This alternative, clean fuel, can replace these methods, which contribute to premature deaths of up to 4 million people yearly.[10] Although some harmful chemicals may still be produced in the ignition process, heavy particulates contained in smoke from burning wood and agricultural wastes are drastically reduced when burning a refined bio-oil.[11] Furthermore, the greater efficiency of bio-oil in electrical and cooking generation decreases time spent on collecting biomass.[3] Also, adding that the lack of preparation needed to prepare the biomass for the ablative units, further decreases time spent on fuel collection.[12] Although there may be increased time needed to wait for refined oil (unless a mobile and easy to use refinement add-on is developed), the small amounts of biochar produced may be able to substitute traditional fuels as an immediate and cleaner source of cooking/heating fuel while the bio-oil is refined.[3]

Case studies

Underground Lignocellulosic Biomass Reactor

In 2012, there were 300 million metric tons of lignocellulosic biomass* available in the U.S. alone. As a whole, it is the most abundant renewable feedstock, one of the cheapest, and does not compete with food resources.[13,14] Researchers at the University of Washington invented a new reactor which utilized Beetle Killed lodgepole Pine as a feedstock. Results from experimentation found that 98% of biomass was recovered, with 51.1% of that being light bio-oil. One breakthrough was that grinding and drying pretreatment of biomass was eliminated. Before, there were minimum particle size requirements that would have to be maintained using mechanized equipment for precise sizing. This further cultivates a path towards mobile units that can be run much more efficiently and without high labor input. Likewise, this exponentially decreases mechanized preparation costs by over 85% to less than US$0.50. Researchers concluded that with further work, the novel reactor can be moved into a mobile unit.[3]

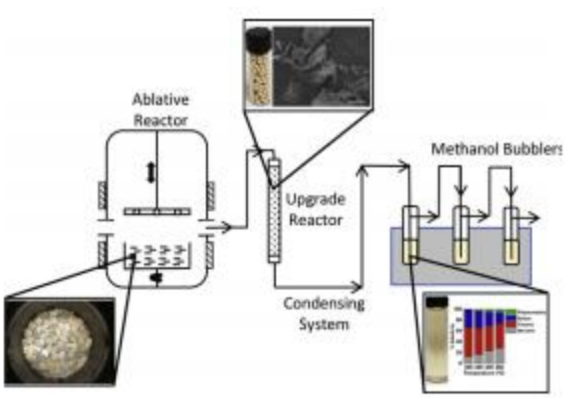

Figure 1. *Novel Ablative Reactor. Photo Credit: Wise et al. 2019.*

Germany-California Reactor

In 2002, the private company PYTEC developed an ablative pyrolysis reactor at laboratory scale in Germany that operates at a 15kg/h capacity. Oil yields are between 50-70% on a dry feed basis. With a need for renewable fuel technology and an oversupply of biomass, California was a prime candidate for a pyrolysis project. Because of the success of the reactor, an Ablative Fast Pyrolysis System was able to be transported through module units to California in 2020. The portable system has a biomass capacity of 500kg per hour and produces 200L of bio-oil. This existing demonstration proves the transportability of pyrolysis reactors through modular design. This design model allows for ease of installation with no unexpected costs and can be fit into standard ship containers, allowing transport through trucks and trains. Additionally, the California reactor works continuously through a computer operated system, requiring little to no manpower. This allows the system to operate so that it does not need to be opened or adjusted during biomass input, which can help inputs reach economies of scale. These existing reactors portray the scalability with modular structure and the feasibility of pyrolysis in practice.[15]

Figure 2. *Germany Plant Reactor. Copyright 2020 Biogas Energy Inc.*

Policy recommendations

The initial funding efforts should be taken-on by multiple entities at local, regional, and national levels, by non-governmental organizations (NGOs), governments, and private investors. Specifically, funding efforts may be most successful by seeking subsidization from countries, companies, and other organizations with a foundational knowledge in ablative pyrolysis technologies.

Current Recommendations:

The best course of action is to implement investments in continuing the research of ablative pyrolysis, which will

- incentivize more scientists to establish a greater foundation of experimentation to advance the technology further;
    - fund universities and other institutions to develop practical mobile units;
- Once progress is made in the implementation of mobile units, these can be transferred globally.

Further expand on the applicability of the economies of scale to achieve high efficiency and reduce overall costs.

- Including investing in faster production of biomass materials.

Anti-Incineration laws should be updated to reflect the current scientific progress in the varied thermochemical conversion methods.

- A historic aversion to incineration from both lawmakers and the public have often resulted in laws limiting the implementation of pyrolysis technologies;
- Pyrolysis is often categorized with incineration waste management methods, but does not foster production of CO_2 and other greenhouse gases;
- Anti-pollution laws should accurately reflect the changing scope of thermochemical energy conversion technologies.
- An all-out ban would reduce the capabilities of ablative to be fully implemented globally.

Encourage the use of pyrolysis technologies for biochar production as an introduction to the benefits of the technology.

- Biochar focused pyrolysis can be more cost effective, is easier to implement, and already has numerous policies and systems in use.
- Biochar production and use can help policy makers and community members become educated on the differences between pyrolysis and incineration, leading to a greater willingness to implement and fund more advanced pyrolysis technologies for biofuel production.

Figure 3. *Inputs and outputs of ablative pyrolysis. Biomass inputs are converted into biochar or bio-oil that can be sent to a refinery to produce fuels. Pyrolysis reactor: Copyright 2020 Biogas Inc*

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Saltwater greenhouses

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Key Messages

Saltwater Greenhouses (SWGH) have the potential to help regions that are affected by food and water insecurity by allowing them to grow food using seawater/brackish water and sunlight.

Benefits of implementing a SWGH system:

- Using desalination as a source of freshwater will mean not having to rely on freshwater for agriculture and not having to over extract groundwater.
- Using solar energy for desalination will reduce theuse of fossil fuels in these systems.
- With proper implementation, a region can grow its own food and reduce imports.

Barriers to implementing a SWGH system:

- The main barriers are financial, especially the large initial investment required to get a SWGH system established.
- Farming subsidies are a barrier to implementation because they discourage innovation in farming.
- SWGH systems must avoid dumping brine (a byproduct of desalination) back into the oceans and must either use the brine commercially or dispose of it in an ecologically sound manner.

Introduction

Over 2 billion people live in countries experiencing high water stress.[1] Worldwide, about 70% of freshwater is used for agriculture.[2] Furthermore, outdoor unprotected food cultivation can demand more than four times as much water as indoor or shaded cultivation[3]. Greenhouse production is a common agricultural method. Depending on the crops, greenhouses have reduced crop water requirements from 50%- 90%.[3; 7]

Saltwater Greenhouses (SWGHs) are being poised as an up-and-coming solution for sustainable agricultural production in water scarce regions- mainly sunny, costal, arid regions and marginalized lands. The goal of this policy brief is to discuss how SWGH could fit into the overall process of increasing water and food security in an afflicted region through a social and environmental impact framework. This methodology considers how the intervention of SWGH affects social-ecological and socioeconomic systems. The application and transferability of this novel technology will be different according to region. This brief draws from two case studies: the SWGH of Red Sea Farms in the wealthy country of Saudi Arabia and a SWGH project in Somaliland, an area of low economic prosperity.

Saltwater Greenhouse Technology

Saltwater greenhouses were first conceptualized by Charlie Paton and the Seawater Greenhouse company at their first site in Tenerife in the Canary Islands in the early 1990's. SWGHs mimic the water cycle by pumping in salt or brackish water that is evaporated to cool and humidify the interior. This creates a microclimate that requires less water for crop needs. Solar power can be used as their main energy source. The process includes solar distillation to create fresh water for crop irrigation.[5] Another variation of this technology is being implemented by Red Sea Farms. They are using genomics for salt tolerant crop cultivation rather than desalination irrigation.[6]

Advances in Technology

Saltwater greenhouses have had pilot projects over the past couple decades in hot, arid, coastal areas. Due to advances in condenser design, building material, structural improvement[5] as well as desalination tech and renewable energy, they are becoming more feasible, even in off grid scenarios.[7] To increase efficiency in engineering and food production, operators of SWGHs are utilizing Internet of Things to receive and send large amounts of info, machine learning algorithms to inform management, and sensors to help control facets of the greenhouse environments like temperature, irrigation, and fertilizing.[8] 5G enabled Smart Irrigation will provide major contributions to greenhouse automation by providing access to real time and precise data about the internal greenhouse environment. This will allow for more efficient use of resources like water and fertilizers.

Another area researchers are making great strides is in desiccant cooling.[6] This is a process of dehumidifying air in order for it to have more space to evaporate water into and achieve better cooling results of the interior of the GH. Mastering desiccant cooling would enable the potential to install SWGHs in tropical, humid areas by the sea as well as arid places, thus, increasing the range of applicability for the technology.[8]

Environmental Impacts

The main environmental impact of SWGHs would be the consequences of brine disposal because disposal can disrupt ecosystems, especially in semi closed areas.[9] According to data from Seawater Greenhouse Ltd. the byproduct of desalination by the SWGHs is a brine solution that is twice as saline as the original saltwater. This solution can then be dealt with in a variety of ways ranging from disposal back into the ocean to commercial uses like mineral or salt extraction. According to another expert, a researcher in the field of water use in arid regions, the brine solution can be safely disposed of back into the ocean as long as it is spread out over a large area.

The prevention principle, an aspect of social and environmental impact assessment, states that it is preferable and cheaper in the long run to avoid a negative ecological or social impact of an action rather than fix damage after the fact[10].

Since disposal of brine back into the ocean has the potential to be carried out incorrectly (by concentrating the brine in a small area), the prevention principle would advise that to avoid ecological damage, reuse or responsible disposal of the brine to avoid ecological damage, should be prioritized.

Potential Solutions

A study conducted in 2000 investigating the uses for brine leftover from desalination plants in the UAE and Oman suggested that commercial uses include recovery of minerals like salt and magnesium, production of materials such as caustic soda, brine shrimp cultivation, or irrigation of salt tolerant crops. Unfortunately, many of the desalination plants do not produce enough brine to justify the commercial uses of brine.[11] Therefore, until the SWGHs are scaled up to produce enough brine, commercial uses for brine will not be feasible. Until then, disposal of brine by using evaporation ponds to drastically reduce the solution's volume is the best course of action when it is used to precipitate salt.[12] However, seepage from evaporation ponds can be a problematic issue.[9]

There is also research being done to investigate whether the brine solution can be used as a desiccant within the SWGH system.[8; 11] If this is successful, it would allow for the brine solution to reduce humidity inside the SWGH, which would make desalination by evaporation more feasible, even in tropical areas with humid climates.

Economics

A majority of countries that are food and water insecure are unable to afford the initial investment required to set up SWGH systems.[11] For example, one of the current projects being run by Seawater Greenhouse Ltd. is a SWGH system in Somaliland. The especially severe water scarcity of these regions leads to food insecurity, which contributes to a reliance on imports[13] or external food aid. Climate change, pollution, population growth, and weak institutions exacerbate water scarcity and could increase chances for conflict over dwindling resources.[17] Somaliland is unable to invest in SWGH due to financial constraints. The current project, which is not large enough to significantly alleviate the food insecurity of the region, is being funded by the UK government with a partnership with the NGO PENHA (The Pastoral & Environmental Network in the Horn of Africa). However, it will require significantly more investment (millions of dollars) and greenhouse space (tens of km^2) for the project to make Somaliland self-sufficient[13].

A very different example is Red Sea Farms in Saudi Arabia. Up to 70% of the initial funding will be loaned to the group by the Saudi government.[8] During these two years, the system will have a chance to get established, the workers will be trained in greenhouse maintenance and operations, and produce will be sold to help repay the loan.[8] Currently, produce from these GH is being sold online, in local places like grocery stores, restaurants, and hotels.[8] Red Sea Farms currently has two 10-hectare GH running- one in Saudi Arabia and one in the UAE. They hope to expand to 100 hectares in five years' time.[8] Once the operation reaches 30 hectares, export markets will have to be identified. It is expected that the operation will create enough return on investment to provide a profit in 3.5 years.[8] If an initial investment is provided for regions like Somaliland, then a similar financing mechanism will be able to help less financially capable regions establish similar SWGH systems and become closer to adapting this technology.

Scale

The scale at which each project is implemented is an important facet of economic feasibility. Economic analysis will vary depending on site location type of desalination tech.[7] For example: use of specific materials and structural design allowed for a decrease in cost for the Somaliland project. Additionally, desalination technology and renewable energy are also improving and becoming less expensive.[11] Improved desalination technology combined with renewable energy and efficient irrigation can enable larger scale agriculture.[11]

Benefits of Scaling Up

Scaling up the operations of a saltwater greenhouse would make them more feasible and cost effective in terms of both construction, marketability, and environmental impact (as brine could be commercially used). Implementing SWGHs at a larger scale would allow the technology and individual components to be purchased/constructed at a cheaper price per component. Training employees in greenhouse operation and maintenance would also be simpler at this scale. This means that as the initial investment amount increases, so does the return on investment. Scaling up the operations could also open up the possibility of more efficient setups. For example, a single large desalination unit could provide water for multiple greenhouses.[11] This would also increase the overall output which would further increase the marketability of the system.

A typical SWGH will not have to purchase freshwater, fossil fuels, and additional cooling, heating, and desalination equipment. This means that both its operating and fixed costs will be around 10 to 25 percent less than those of a greenhouse that does not rely on desalination.[10]

The scale will also affect the produce each greenhouse can output. Currently estimates of production vary depending on several initial factors such as local costs of land, materials, and labor. The first commercial scale SWGH in Port Augusta, Australia is an excellent example of this. When the facility was first established in 2009 by Seawater Greenhouse Ltd. it was 2,000m^2 and was capable of producing 100,000 kilos of tomatoes a year.[14] The facility is now operated by Sundrop Farms and has been scaled up further to 200,000m^2.[15]

Social Impacts

Small Holder Farmers

Interview data mentions how regional politics and subsidies play a huge role in agriculture innovation competition.[8; 11] Different countries have different subsidies and import/export economies. For a SWGH to be successful anywhere, commercial viability is essential.[11; 13] While many SWGH's are starting to emerge singularly, they are anticipated to fulfill large scale industrial style farming.[8] Due to the cost and technical ability, it is not feasible for smallholder farming. As this tech becomes more widespread, there needs to be a conscious and intentional balance between this form of large scale industrialized and smallholder farming.[8] SWGH should not displace small farmers or compete with markets that support their livelihoods.

Recommendations

- For this technology to be deployed, there should be a way to provide investments or loans for the initial phase of SWGHs. This will help them get established and, in time, the loan will be paid back. This will allow governments of areas that are financially challenged to be able to afford to establish a SWGH system.
- The principle of multisectoral Integration, a concept from social and impact assessments, states that social issues should be considered in projects, policies, infrastructure programs and contributions to skill development and capacity building in the community.[10] SWGH will interact with regions differently, therefore, the cultural aspects, existing livelihoods, and who has access to the technology should be considered (See flowchart).
- To avoid environmental damage from SWGH operations, incorrect brine disposal should be prohibited by local governments. There are solution-based projects on the horizon that look at harvesting salt, mining it for minerals[9], and using it as a liquid desiccant to be fed back into the greenhouse cooling system.

As SWGHs begin to become more widespread, a thorough, regional stakeholder analysis should be done to understand the impact of a SWGH on multiple sectors prior to implementation. It should include participation from communities, not just project funders

Gender Implications

Interview data states that both SWGH projects in Somaliland and Saudi Arabia are hoping to create jobs from these projects, especially for women.[8; 13]This would entail maintaining plants, harvesting, sorting, and packing.[8; 13] The agriculture sector employs the most women in middle and low income countries.[16] There is a need to provide access and skills involving technology in the workforce.[16] SWGH are a form of technology that require more specialized training to maintain and operate the greenhouses and the equipment within. As SWGH systems elevate and transform agriculture, the position of women as workers must also be elevated and transformed so they are not left out of the process of modernization. While economic empowerment is important for women worldwide, so is access to technical training and opportunities to upskill.

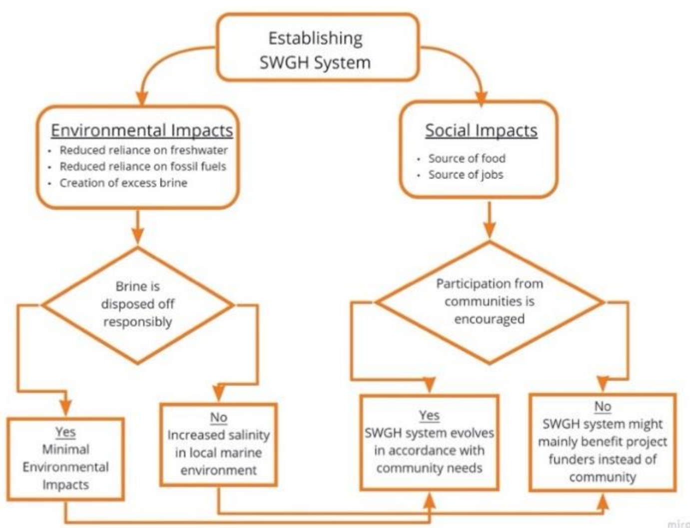

Figure 1. Flow Chart Adapted From Brymer et al, 2016[18]

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Chemical technology for the future of plastic recycling

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Key messages

Successful implementation and development of chemical technologies are essential for using natural resources efficiently and achieving a circular economy.

The roles of governments are highlighted in developing countries in institutional processes as well as in connecting relevant industries in the plastic supply chain.

Separating solid waste at source will still be a goal for developing societies since it helps recover plastic better in both quality and quantity, and this should be oriented to recovery of plastics

Introduction

Although plastic is intensively used, about 60% of the used plastic products become waste that go to landfills or end up in the environment.[1] The maximum recycling rate for plastic that has been achieved is 30% in developed countries with advanced infrastructure and regulations.[2] Up until now, the predominant method of plastics recycling is mechanical recycling. This technology is not capable of recycling all types of plastic, requires clean raw materials, and its product quality is downgraded during its life cycle. However, most of the raw materials in developing countries are not clean due to insufficient separation of waste at sources. Therefore, recycled plastic products are low in quality.

The use of chemical technologies for plastic recycling provides an alternative to mechanical recycling, could help in meeting circular economy targets, and results in recycled material of higher quality. Chemical processes have higher tolerance to mixed and contaminated plastic waste streams than mechanical recycling and can break down polymers into single monomers to produce a high-quality product. Thus, chemical recycling technology is highly recommended for the future of plastic recycling. Currently, there is a lack of support for chemical recycling of plastic. A knowledge gap to be filled includes technical, social-political, and environmental challenges for greater utilization of plastic recycling by chemical methods. This brief explores multiple aspects of chemical plastic recycling, including applications and challenges. It includes a case study in Ho Chi Minh City, Vietnam, and suggests possible policy approaches.

Chemical Plastic Recycling and Why

Chemical recycling refers to processes in which a plastic polymer is chemically converted to monomers or petroleum liquids and gases.[3] In the case of monomers, they are further processed (e.g., by distillation and drying) before being used for other organic industries.[4]

Challenges of Chemical Plastic Recycling Technology

Besides the benefits, there are also challenges with regards to chemical recycling technology that need to be addressed. The following subsections analyze important economic, technical, and environmental challenges.

Economic challenges

Economic inefficiency has been identified as a major concern. Firstly, polymers synthesized from recovered monomers from chemical processes are more expensive than virgin materials because of the raw material cost, capital investment, and scale of operation.[20, 21] Failure to incorporate environmental cost and benefits equally across industries prevents manufacturers from choosing recycled material inputs.[5] Secondly, the high cost of chemical recycling is linked to financial matters, in particularly investment capital. In order to have positive profit, large investments (e.g. for big plants and expensive technologies), an aggregation of stable sources and large amounts of waste are required.[5, 9] It has been estimated that a minimum capacity of 15,000 tons per year is required to achieve economic feasibility for a Polyethylene terephthalate (PET) chemolysis facility.[9] Thirdly, a market for recyclates has been identified as an important factor influencing the economic efficiency. Without a market for recycled products, installations of chemical recycling facilities become unfeasible.[8, 20]Fourthly, sustaining the chemical recycling facilities is another concern. Disruption of some parts of the plastic supply chain, such as between plastic scrap suppliers and recycling plants and between recycling plants and recycled product consumers, would happen if long-term commitments between the parties cannot be met.[9] Finally, inadequate transparency with regards to reporting the recycled material content would also negatively influence recycling motivation (e.g. for reputation, reward, or competitive advantages) among manufacturers.[5] This is because manufacturers that work at different levels of effort bear extra pressure from external factors such as market and regulations.

Technical challenges

Only perfectly separated plastic can be converted to qualified virgin materials.[1, 6] This is because different plastic types are not compatible with each other due to their inherent immiscibility at the molecular level.[7] For instance, chemical processing of PVC-contaminated PET will reduce the quality of recycled PET resin owing to the evolution of hydrochloric acid gas and reprocessed PET. Conversely, a small amount of PET in a PVC recycled stream will significantly reduce the value of the recycled material. However, not all plastic is the same, which cannot promise an ideal chemical recycling process.[5] Chemical recycling by pyrolysis of mixed plastic generates diesel and naphtha, which should be further refined before distribution and consumption.[5] If these recovered products are used as combustion fuels, a very short life of plastic recycling products could be obtained. Another alternative is to convert oil to plastic at a low rate of about 10%.[8] The rest can be transferred to refinery plants to produce combustion fuels.

Environmental inefficiency

Despite effective separation, total removal of PVC from plastic waste mixture can be achieved. During the pyrolysis, generated acid gases (e.g., HCl) would degrade the quality of the recovered products, hence it needs to be removed using neutralizing agents ($CaCO_3$, CaO, $NaHCO_3$, $Na_2(CO_3)_2$ or NH_3). Consumption of such chemicals is not environmentally friendly.[9]

Case Study of Ho Chi Minh City

Current situations on plastic waste generation and recycling

Vietnam has experienced a rapid increase in plastic consumption, from 800 tons per day in 2,000 to 2,500 tons per day in 2018.[10] It is also one of the five countries that contribute up to 60% of marine plastic pollution.[11] Over 80% of plastic products in Vietnam are produced by provincial governments through supporting policies, regulations, programs, workshops, and pilot projects, totaling 6.9 million tons of virgin material (2018). [2] Annual plastic waste generation of Vietnam in a five-year period (2014 – 2018) is estimated to be at least 3.27 million tons, of which approximately 20% is recycled and the rest goes to landfills or the environment.[2, 22] In Ho Chi Minh City, the plastic waste generation is 250,000 tons per year, of which 19.2% is disposed in landfills[10] and 18.2% is recycled.[23] Thanks to scavengers who earn their livelihoods from picking up and recycling, valuable plastics (e.g., PE, PP, and PET) could be recovered from mixtures of solid waste. However, this amount is small in comparison to total plastic generation and unclean due to poor separation and handling at source.

Currently, plastic recycling is dependent solely on mechanical processes, for which sufficiently clean and separated streams of mainly clear rigid plastics are preferred.[24] The existing (mechanical) recycling facilities are of small and medium scales where attention has not been paid to environmental handling. These facilities that utilize a domestic supply of plastic waste fail to sustain efficient performance due to high costs for further sorting and washing.[8, 14, 21] Therefore, many of them rely heavily on imported plastic scrap, mostly PE and PET, which results in an increase of over 166% and 137% respectively, in 2017.[2] On the other hand, mechanical recycling technology has raised environmental concerns due to a high loss of inputs up to 30 – 40% and releasing VOCs and microplastics into the environment.[25] As a result of these adverse environmental impacts, the acquisitions of sites and approval for new investment projects using this technology face numerous obstacles and barriers from authority agencies in these years.

Advantages of promoting chemical technologies for plastic recycling

The development of chemical recycling technologies is essential and advantageous in the context of Vietnam towards pursuing SDG 12 “responsible consumption and production" and SDG 11 "sustainable cities and communities. The central government of Vietnam has postulated regulations favoring waste recycling in terms of land supports and financial incentives.[26, 27] This is followed by efforts made by city or residents from the plastic recycling industry. Regulations on input qualities in order to reduce plastic consumption and promote plastic recycling.[12, 13] In the coming years, the authority of Ho Chi Minh City plans to promote new or advanced technologies for waste recycling and treatment, which is integrated in the City Programs on Environmental Pollution Mitigation from 2020 to 2030.[14]

According to the Vietnam Plastic Association (VPA), the demand for plastic is about 5 million tons per year (2016), and is imported mainly from Afghanistan, Korea, Taiwan, Thailand, China, Japan, Singapore, Malaysia, and the UAE.[15] Meanwhile, domestic suppliers can afford only about 20% of demand.[15] The cost for imported plastic materials is highly dependent on exchange rates with fluctuations. This is a challenge for those that rely on imported sources, but an opportunity for domestic plastic suppliers. Tapping the full potential of domestic plastic sources can therefore solve the problem of material price. It further stimulates the plastic recycling industry as a whole where chemical technologies have a chance to make great contribution.[16]

Institutional barriers

Although the Vietnamese institutional system encourages plastic recycling, some barriers exist in terms of its clarity and comprehension.[12] In particular, Ho Chi Minh City encourages the use of incineration with energy recovery and waste recycling technologies to achieve a treatment rate of 80% by 2025 and up to 100% by 2030.[14] Accordingly, municipal solid waste is separated into two types, recycling waste and the non-recycling waste.[17] The former type includes multiple recyclables (e.g. plastics, metal, paper, rubber). This means that plastics will be in mixtures of recyclables before being further sorted and cleansed for recycling. Although chemical processes can receive unclean and mixed plastics, the value of recovered products from such inputs are not as high as from clean and well-separated inputs.[8] In Japan, for instance, beverage packaging is label-off, cap-removed, and cleansed by consumers before being collected for recycling. Therefore, undetailed and unclear guidelines for solid waste separation will result in failures in achieving the solid waste management objectives, including promoting chemical recycling.[14] Guidelines for handling the emissions and wastewater are necessary to meet the demand of recycled plastics, as inputs to further manufacturing industries, which are products standards. Also, experts in barriers in implementing and managing plastic recycling technology.

Infrastructural barriers

As discussed, plastic is unclean when following the guidelines for solid waste separation of Ho Chi Minh City. This limits the quantity of plastic supply for recycling. Additionally, since imported plastic will be fully banned by 2024,[2],the alternative supply source will be interrupted. Therefore, requirements of large-scale and stable supply of plastic are also challenging for the installation of chemical recycling facilities.

In addition, there has been no large-scale project on chemical recycling of plastic waste in Vietnam, with the majority taking place at a laboratory scale.[8, 28]

Social and economic barriers

Several social and economic factors may influence feasibility of chemical recycling technology. Firstly, most communities in developing countries have not formed the habit of separating waste. This leads to unoptimized efficiency for chemical recycling with products mostly being comprised of fuels. Meanwhile, crude oil prices in the world range from US$20 to US$30 per barrel, which is considered cheaper than recovered fuels. This will discourage chemical recycling.[8, 21] Secondly, relevant industries in the plastic recycling supply chain, such as the chemical industry, petrochemical industry, and material industry in Vietnam are undeveloped. Recovered materials from chemical recycling serve as inputs to chemical and material industries for re-polymerization (e.g., polystyrene from styrene) or production of new materials (e.g., carbon nanotubes from chemical processing of black plastic).[1] Petrochemical industry is sometimes needed for the refinery of fuel products from chemical processing of mixed plastic.[8] Hence, the chemical recycling industry for plastic will depend on other nodes in the plastic supply chain.[8] Last but not least, products from chemical recycling are still high in price, which will be discouraging investment in these technologies.

Policy Implications

Although various mechanical technologies for plastic recycling have emerged, more efforts would be needed expected for it to grow faster than the supply.[16] This creates a chance for developing chemical technologies for plastic recycling. In order to do so, authority agencies in developing countries, especially the central government, need to take into consideration the following recommendations:

Institutional supports are significant in developing countries which are characterized by more top-down and centralized governance structures.[12, 14] Strategies (e.g., promoting chemical recycling technology) and goals for recycling (e.g., types of waste to be recycled) should be specific and clear, and guidelines for plastic separation and recovery should be goal-oriented. Priorities in types of plastic subjected to chemical recycling (e.g., beverage packaging plastic), as well as distribution channels (e.g., retail chain store) should be well identified.

Separating solid waste at source should be a goal for developing societies since it helps recover plastic better in both quality and quantity. Solid waste separation at source should be objective-oriented (e.g., to recover and recycle certain types of plastic) and strengthened via educational programs at early ages and community education.

Technological issues play a significant role in the successful development of chemical plastic recycling. Transfer of technologies can kick off the application of chemical technologies in the current context. Long-term strategy should promote up-scale research,[8] catalyst research[18] and foster research collaboration with countries that have experience in chemical plastic recycling technologies.

Promoting chemical recycling technology should be integrated with other industries in the supply chain. The chemical industry, petrochemical industry, and material industry are potential consumers of recovered materials from chemically processing plastic for the synthesis of new polymer materials. The new materials can be supplied to the beverage industry (e.g., Coca-Cola, Pepsi) and consumer industry (e.g., Unilever, P&G) or the packaging suppliers of those industries. These manufacturers could lead in shaping social norms with regards to the use of recycled plastic.[19]

The emphasis of chemical recycling is on converting plastic waste into starting materials for repolymerization, and this is mainly led by industries or heavily dependent on their involvement.[19] Enhancing the participation of the plastic industry and other relevant industries requires government support in terms of encouraging policies. In Vietnam, governmental authorities at national, provincial and city levels, such as Congress of Vietnam, MOIT, MOF, MONRE, and MOST, have significant roles in directing the social and economic development and in such institutional processes.[12] Accordingly, regulations (e.g., the level of recycled plastic in products), guidelines (e.g. solid waste separation, deposit – refund system), standards (e.g. recycled products, emissions from plastic recycling sector), and incentives (e.g., land and financial supports) are needed in to promote chemical recycling.[12, 16, 29]

Chemical recycling surpasses mechanical recycling in terms of a wider range of input quality to be accepted, including mixed plastics, flexible plastics, films, and those which are difficult to process mechanically (e.g., PP, PUR, PA). Meanwhile, mechanical recycling can produce higher-end products.[24] From the above interpretation, chemical recycling technology is strongly recommended for the future of plastic waste recycling in Vietnam.

To develop a market for recovered materials from chemically processing plastic, it is necessary to have both supplies and demands that compete fairly and are social-oriented. Therefore, the roles of large corporations (e.g., Coca Cola, Pepsi, Nestlé, IKA, NGO) as well as governments (e.g., MoIT, MOF, MONRE, MOF) need mutual support to shape and create thrust to the recycling market. With that, plastic recycling by chemical technologies can be applied.

In the development of the plastic recycling market for chemical technology, it is necessary to research on a laboratory scale (e.g., enhance technology, recovered materials, reduce pollution, plastic waste input) to first come up with specific technologies appropriate for the context and to bring high value towards SDG12.

At the same time, it is necessary to set out standards on wastewater, emissions and waste generated from the operation of plastic recycling technology by mechanical methods.

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F. Specific solutions and updates on country experiences and activities

Integrated technological solutions for the SDGs – Two case studies

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G-STIC

G-STIC offers a platform to discuss and analyze technology clusters with a clear focus on identifying integrated technological solutions that can substantively contribute to the achievement of several SDG targets. To do so, G-STIC brings together policy makers, researchers & scientists, technology providers, civil society representatives and entrepreneurs from different sectors.

Focused on interconnecting practices between sectors such as energy, (waste)water and health, G-STIC promotes the active deployment of integrated technological solutions at scale. G-STIC builds on the expert knowledge and know-how available through both regional and global organizations, networks and events. As such, G-STIC creates added value by opening up a space for cross-sector solutions that contribute directly to addressing several SDGs.

Integrated technological solutions

Integrated technological solutions focus on working across and beyond traditional sectors, and aim at delivering real benefits to people, communities, businesses and society at large. Integrated technological solutions address several aspects related to climate, circular economy, education, energy, health, oceans and water simultaneously.

The critical issues that need to be addressed if we want to move forward with integrated technological solutions realizing the SDGs, include:

- What existing technologies can help us achieve the SDGs a part of integrated solutions?
- Why, how and where are these technologies currently used? What makes them successful?
- How do we bring these technologies to the market at scale?
- What are the enablers and hurdles to accelerate their adoption? How do we engage stakeholders to overcome the hurdles and leverage the enablers?
- What are the roles of government, civil society and the private sector in the transition towards deploying integrated technological solutions to achieve the SDGs?
- What policy, institutional and regulatory changes and new frameworks are required to accelerate the uptake of these technologies and to scale the deployment of integrated technological solutions?
- What are the investment needs and funding opportunities to accelerate the development of these technologies and to ensure they become readily accessible?
- What (innovative) financial models and mechanisms can be used to initiate and scale the use of transformative technologies?

Examples of cross-sector approaches to integrated technological solutions

'Safe water for all' - Collecting and treating wastewater helps improve the health of people and the environment. Turning wastewater into drinking water, bioenergy or fertilizer contributes to water security and helps produce food and energy.

'Health for all' - Health solutions reach beyond the healthcare sector and include delivering adequate drinking water, nutritious food, sanitation, heating and appropriate education. Affordable and energy-efficient housing with adequate water supply and sanitation also contributes access to health, particularly for the most vulnerable.

'Sustainable housing for all' - Bamboo housing can help provide cheap and disaster-resistant low-cost housing for all. At the same time, bamboo plants help fight climate change by capturing carbon, and reduce erosion, run-off and sedimentation by supporting the management of healthy watersheds. This helps create future water security and supports adaptation to climate change.

'Sustainably use of the oceans' - As the desalination of seawater becomes increasingly affordable, it can provide an alternative clean water supply to households and businesses and help adapt to climate change.

Case Study 1: Anaerobic Digestion by Combining Organic waste and Sewage (ANDICOS™)

Classical aerobic activated sludge treatment is the reference treatment technology for sewage in emerging and developing countries. High amounts of energy are used to oxidize fully the BOD (and a large part of the COD) into CO_2 and water. One kg of COD needs about 1.5 kWh as oxidation energy. This means that on average 15 to 30 kWh energy is used per person per year. Activated sludge treatment leads to high energy consumption, greenhouse gas emissions (CO_2 and N_2O) and high amounts of sludge production (20-50% of the carbon goes to bacterial sludge). Besides dealing with wastewater, sludge management is often of general concern due to a lack of, or poorly operated, treatment infrastructure. Untreated or partially treated sludge is discharged into water streams or dumped into landfills.

In an anaerobic process about 90% of the organic matter (read carbon) can be transformed into biogas (CH_4 and CO_2) and only 10 % is transformed into extra bacterial sludge. Biogas can be converted into electricity and heat or upgraded to bio-methane with subsequent storage or injection into existing natural gas networks. However, the anaerobic process is working inefficiently at COD-levels between 0.1 and 0.5 g/L, which are normal sewage water COD levels. This is the reason why in several tropical or subtropical countries anaerobic treatment is sometimes installed (high ambient temperatures being an advantage) but fails due to inefficient processing and unsustainable exploitation of the generated biogas. In order to achieve an efficient anaerobic process higher COD concentration than the levels in normal sewage is advantageous.

ANDICOS™ (Anaerobic Digestion by Combining Organic waste and Sewage) is an integrated wastewater treatment approach that delivers water re-use and green energy by combining sewage concentration and anaerobic digestion. Membrane filtration is used for concentration of sewage and subsequent anaerobic treatment of the concentrated sewage. The concentrated sewage can be mixed with primary sludge and other organic wastes. Different separation steps and anaerobic treatment systems can be applied (UASB treatment and/or anaerobic digestion) depending on the specific local situation. The filtration step uses IPC™ (Integrated Permeate Channel) membranes to concentrate the sewage water by a factor of 10 to 20. This way 90 to 95% of the water can be discharged or reused for irrigation after post treatment. A high bacteriological removal rate is achieved due to the membrane filtration. The concentrated sewage (5 to 10 % of the sewage water volume) can subsequently be treated anaerobically in a UASB system for example if such a system is available at the sewage treatment site. The concentrated sewage can also (partly) be mixed with readily available organic wastes, such as primary sludge, kitchen waste, crop residues to achieve a feed stream to be treated in an anaerobic digester. Extra addition of organic waste will improve the economic value of the process as it will lead to higher biogas production and in that way to higher electricity production.

Based on scaling up the ANDICOS™ approach to serve an urban population of 20,000 we estimate the following inputs:

- Raw sewage flow: 2500 m^3/day,
- Organic waste flow: 50 ton/day (additional organic waste from outside the community needs to be available).

The estimated outputs would be:

- Energy production: 5922 m^3/day of biogas converts to 15 MWh/day;
- Treated effluent discharged to river or re-used for irrigation: 2375 m^3/day;
- Organic fertilizer: 26 ton/day (assuming 20 % dry matter).

The operational income from the sale of green energy and organic fertilizer will result in positive pay back times. In addition, capturing biogas reduces greenhouse gas emissions in two ways: firstly, preventing uncontrolled methane emissions (from landfill sites); and secondly, generating energy that displaces the use of fossil fuels.

Case Study 2: CO_2 capture: from postponed, cyclic to negative emissions

The IPCC has investigated different scenarios of yearly CO_2 emission trajectories and identified a challenging route to achieve a temperature anomaly of less than 2 degrees Celsius by the end of the 21st century. It is clear that such ambition not only requires gradual diminution of CO_2 emissions from industry, fuel burning and land use, but also the introduction of CO_2 capture technologies, in the form of negative emissions. Starting from 2030, a net reduction of more than 10 gigatons of CO_2 is required per year, of which the half is assumed to originate from 'CO_2 capture and valorization' strategies, reaching net zero CO_2 emission by 2070.

This target setting for CO_2 capture however needs some more attention, in the frame of existing and new CO_2 valorization options, i.e. Carbon Capture and Storage (CCS) allows CO_2 fixation by storing the captured CO_2 underground, whereas its utilization alternative (CCU) only foresees the 'zero emission aspect' in the mineralization route, with for example building materials as end product. Other CCU pathways include the direct use of CO_2 or as feedstock to substitute fossil carbon for the production of fuels or chemicals. Indeed, CCU towards fuels and consecutive burning are just a postponement of CO_2 emissions, if capture from industrial CO_2 point sources are considered as feedstock supply. Nevertheless, by replacing the recovery of oil from below, its refinery and burning of corresponding amounts of fossil resources in the same timeframe, yearly emission from diffuse CO_2 sources like maritime and long-distance transport can be lowered. If the CO_2 is directly captured from air, one can recognize the cyclic and CO_2 neutral nature of such solution. Also in case of CCS, the replacement of Point Source by Direct Air Capture (DAC) would imply an upgrade in its definition as a negative 'CO_2 emission'. DAC offers furthermore the possibility to capture CO_2 from a large quantity of small-scale emitters such as in the transport sector, which account for 50% of the global GHG emissions. A further advantage besides the origin-independent sourcing of CO_2 is the location-independence, which allows to locate the CO_2 capture installation nearby places with most favorable renewable energy prices and/or subsequent utilization needs.

The importance of Direct Air Capture (DAC) is clear in the vision towards a CO_2-neutral society. However, two aspects are to be considered: this technology is still highly energy-demanding, which results in indirect CO_2 emissions on the short term and is suppressed by poor economic viabilities at current scales. Indeed, the recovery of CO_2 from dilute sources, i.e. 400 ppm in air instead of 5 – 15 % in industrial flue gasses, requires significantly higher energy requirements. Opportunities, however, exist to reduce or even avoid high energy-intensity via proper equipment integration and industrial symbioses, i.e. by making use of existing air displacement units and/or waste heat. An advantage of DAC is that the CO_2 recovered is generally free of contaminants typically present in flue gasses, making conversion to new products (fuels or chemicals) less complex.

DAC is a relatively new and innovative technology in early commercial stages. The currently applied technologies can be classified as (i) high temperature aqueous absorption (900°C) or (ii) solid sorbent adsorption. The first process is a continuous approach and makes use of alkaline solutions to capture CO_2 in the form of (bi)carbonates. In a 2-step train, alkalinity is recovered at high temperature and CO_2 is isolated. Potential innovation lies here in the liberation of high-purity CO_2 or bicarbonate conversion into chemicals/fuels, while recovering alkalinity by electrolysis. The latter process has as advantage that the captured CO_2 can be released through low temperature heat (typically <100°C for amine-based sorbents). The relative low temperature requirement allows the use of cheap energy, which can be available as waste heat from industrial plants. An example is the integration of a DAC installation at a geothermal site. The fans from the cooling units of the electric power generating ORC installation at the geothermal site are used to contact the air with the solid sorbents and the geothermal hot water (<100°C) is used to regenerate the sorbent after adsorption.

Further reductions in energy requirement and cost of the DAC process require porous structured sorbents that allow high air flows to contact the sorbent with minimal energy loss (i.e. low pressure drop), have fast and energy-efficient cyclic sorption and high CO_2 sorption capacity.

The captured CO_2 can be stored and converted in a next step, by the combination with green H_2 and production of useful products like methane, which is used locally or easily supplied to the existing gas grid. Opportunities exist in the valorization of high-temperature, exothermal heat (>450 °C), liberated during such reaction, next to low-temperature heat losses (80 °C) in the electrolytic green H_2 production. These flows may address heat demands for residential purposes, next to the regeneration of sorbent in the DAC step. Of course, such concepts are highly sensitive to (green) electricity prices and CO_2 taxes.

Solving real problems with real data: The ITU AI and Machine Learning in 5G Challenge

Thomas Basikolo, ITU

Acknowledgment: I wish to thank my colleagues, Reinhard Scholl and Vishnu Ram – for their support to ensure success during the first edition of the ITU AI/ML in 5G Challenge.

Artificial Intelligence (AI) / Machine Learning (ML is a subset of AI that allows machines to learn from data without being programmed explicitly) will be a dominant technology of the future and will impact every corner of business and society. In particular, AI will shape how communication networks, a lifeline of our society, will evolve. Many stakeholders in the information and communication technology (ICT) domain are exploring how to make best use of AI/ML.

Telecom companies are placing AI at the heart of their digital transformations in order to provide better customer experience, improve operations, and increase revenue through new products and services.

Applying AI/ML in communication networks poses different challenges than applying in, say, image recognition or natural language processing:

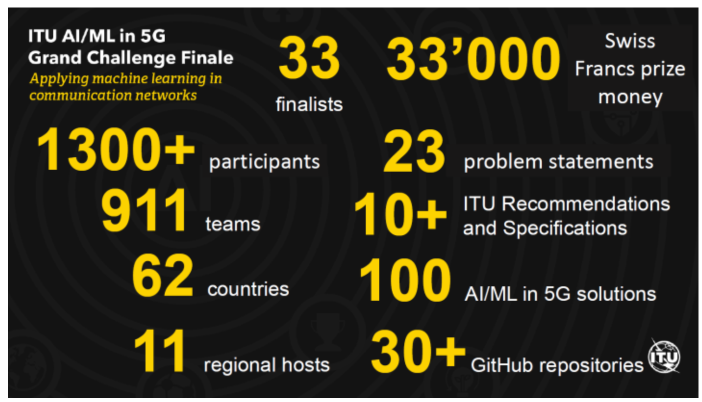
(1) Time scales vary a lot in communication networks: some parameters change on an annual basis (e.g. your subscription to a telecom provider), while others may vary on a millisecond timescale. If your network parameter changes on a millisecond timescale, you need to (re)train your ML model on a similar timescale.
(2) The network environment is noisy, i.e., original signals are distorted by undesirable modifications of that signal.
(3) Computing resources in a network are limited.

Thus, while telecom operators have seen early AI applications to predict customer churn, predict fraud, identify customers for up-sale or cross-sale, the industry has been slower in applying AI in use cases related to networks.

ITU has been at the forefront to explore how to best apply AI/ML in future networks including 5G networks.

5G, combined with AI, will speed up the advancement of the SDGs with significant contributions in healthcare, education, agriculture, energy, manufacturing and transportation among others. The technology will transform these sectors by providing significantly higher speed and lower latency for people, devices and applications. This will improve the systems and procedures in different sectors and enabling innovative technology applications and solutions.

In order to promote the advancement of AI/ML in telco industry through joint efforts, the ITU AI/ML in 5G Challenge was born.



The ITU AI/ML in 5G Challenge[214] rallied like-minded students and professionals from around the globe to study the practical application of AI and ML in emerging and future networks. The first edition of the Challenge was conducted in 2020 with over 1300 students and professionals from 62 countries, competing for a shared a prize fund totalling 33 000 CHF and global recognition.

The Challenge enabled participants to connect with new partners in industry and academia — and new tools and data resources — to solve real-world problems with AI/ML. The Challenge aimed to demonstrate and validate ITU standards. In mapping solutions to ITU standards, the Challenge contributes to the growth of the community able to support the iterative evolution of these standards. The solutions can be accessed in several repositories on the Challenge GitHub[215].

[214] https://aiforgood.itu.int/ai-ml-in-5g-challenge-2020/

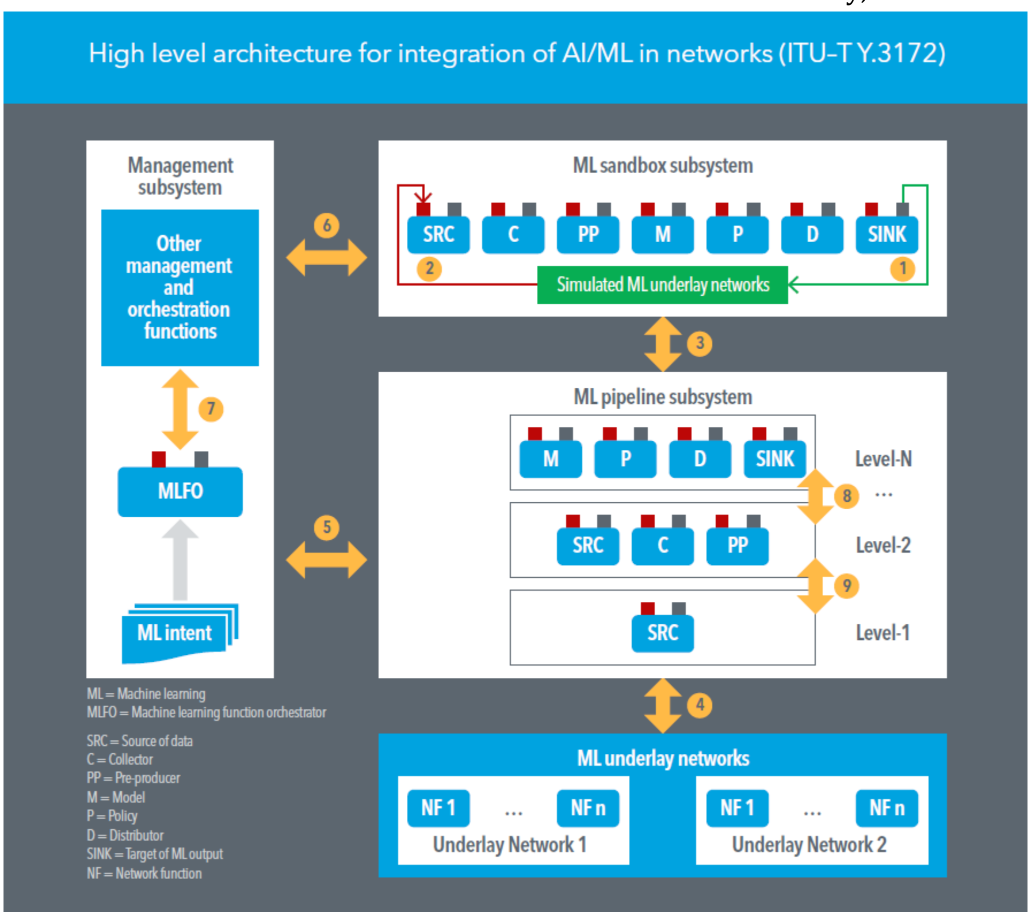
[215] https://github.com/ITU-AI-ML-in-5G-Challenge

Technical tracks

The Challenge addresses problem statements in four technical tracks.

- *A Network Track* challenges entrants to build and train AI and Machine Learning models capable of supporting 5G networking functions.
- *An Enablers Track* calls for innovations enabling networks to take full advantage of AI and Machine Learning models and their outputs.
- *A Verticals Track* asks how 5G-enabled applications in vertical markets such as automotive and healthcare could benefit from AI and Machine Learning capabilities.
- *A Social Good Track* invites innovations capable of accelerating progress towards the achievement of the United Nations Sustainable Development Goals.

Through the Challenge, ITU encourages and supports the growing community driving the integration of AI and ML in networks and at the same time enhances the community driving standardization work for AI/ML. The ITU Challenge enables the collaborative culture necessary for success in emerging and future networks such as 5G and creates new opportunities for industry and academia to influence the evolution of ITU standards.



High level architecture for integration of AI/ML in networks (ITU-T Y.3172)

Why are AI/ML and supporting standards important to 5G and future networks?

Companies in the networking business are introducing AI/ML as part of their innovations to optimize network operations, increase energy efficiency and reduce costs. 5G represents major advances in networking to meet the needs of a very diverse set of applications, across industry sectors. Networks are growing in sophistication and complexity. AI/ML will be a key tool in managing this complexity. The ITU–T Y.317x standards provide versatile toolsets to support AI/ML integration in tune with network evolution. Standard "toolsets", built to be adapted to evolving user requirements and a broad scope of use cases, are also found in ITU standards in fields such as multimedia, security, blockchain and quantum information technology.

The Challenge furthermore aims to provide a reference implementation of an end-to-end ML pipeline as defined by ITU–T Y.3172. Such reference implementations could include notebooks for ML coding and integration; tools for data processing and management; and tools for ML model selection, training, optimization and verification. We also aim to enable access to ITU–standard toolsets for initiatives such as plugfests and hackathons and to set the stage for collaboration in open-source projects and standardization work.

A learning experience for all

Data availability is a key challenge to be navigated when bringing together a global community to innovate with AI/ML. For the ITU Challenge, fifteen problem statements were open to all participants. Eight were limited to participation under conditions set by their hosts.

The data sharing guidelines of the ITU Challenge incorporate a wide range of perspectives from industry and academia on access to real network data, synthetic data and open data. The guidelines describe measures to enable data sharing in view of different classifications of datasets, pre-processing steps (including anonymizing) and secure hosting of data. We also saw the best outcomes achieved in close collaboration.

The Challenge highlighted that problem statements are best positioned for success when supported not only by the necessary tools and data resources, but also by close collaboration between participants and our regionals hosts, namely the universities and companies which provided the problem statements.

Our priority was to create community value in the field of AI/ML. In our work to offer participants a level playing field, ITU and our partners developed tailored workflows delivering participants a unique, customized Challenge experience.

ITU engaged participants in technical roundtables and webinars to provide expert guidance in addressing problem statements and the value of new ITU standards in support. Together with our regional hosts, we reached out in local languages, connected participants with mentors and maintained interactive discussions on our Slack channel.

Why we need new partnerships for new data

Access to high-quality data remains a key challenge facing innovation in AI and machine learning. Synthetic datasets built with simulations have played an important part in the ITU AI/ML in 5G Challenge due to lack of real data from operating networks. Some problem statements were very relevant and well-formulated but lacked any source of data — participants needed to find and provide their own datasets as part of their solutions.

While most of the problem statements were open to international participants, some were restricted to national competitions, due to data protection regulations at regional level.

To achieve accurate functional ML/AI algorithms, high-quality input data is essential.

Extensive, collaborative datasets from operating networks would be ideal inputs to AI/ML algorithms. However, at present it is very difficult to obtain such collections of data from commercial network operators. Moreover, effort needed to collect specific data, preprocess it and anonymize it is an overheard. Operators need to protect the privacy of their customers, and they are also hesitant to share data containing business-critical information about the operational status or performance of their networks.

Up to the challenge in 2021?

Preparations for the ITU Challenge 2.0 are in full swing, driven by a core team of challenge management board members, judges, promotion partners and sponsors. We will continue to encourage new partnerships in AI/ML and tune guiding principles for the sharing of tools and data resources necessary to enable these partnerships. We are welcoming new partners and new problem statements, and new tools and data resources. We are creating new opportunities for industry and academia to solve problems together, and new opportunities to influence the direction of standards development and application. Contact us at ai5gchallenge@itu.int to participate in the problem-solving, judge some of the interesting submissions, promote the challenge, sponsor a prize, or mentor a few students.

The Inclusive Digital Model (IDMODEL) Project

Xiaolan Fu, and Elvis Korku Avenyo (University of Oxford), Pervez Ghauri (University of Birmingham), Xiaoqiang Xing, (University of International Business & Economics, China)

Overview

The Inclusive Digital Model project aims to research into a new business model that seeks to enable marginalised people in developing countries to generate income and empower themselves by sharing their skills and experiences using a digital platform.

The IDMODEL project is awarded and funded by the Economic and Social Research Council's Global Challenges Research Fund (ESRC-GCRF), and led by the Technology and Management Centre for Development (TMCD) at the Oxford Department of International Development (ODID) – University of Oxford and the Department of Strategy and International Business at the University of Birmingham.

Project partners: SBK Foundation; University of International Business and Economics; Ministry of Foreign Affairs, Bangladesh; Kuaishou Technology Co., Ltd; and Bangladesh Network of NGOs for Radio and Communication (BNNRC).

While digital business models have the potential to enhance the capabilities of small-business owners and drive economic growth, there are several gaps in our understanding of how this process works. The IDMODEL project brings together research from the fields of technology, development studies, and business studies to fill these gaps. The project aims to investigate the role of digital technologies on inclusive development based on case studies in China and Bangladesh. The IDMODEL's 'Haate Haat' app, is content-based and aims to empower marginalised people in Bangladesh to create both economic and social value through the sharing of their skills and experiences.

This policy brief summarises the main findings and key policy recommendations emanating from China 'Kuaishou' and Bangladesh 'Haate Haat' cases. The brief incorporates the views of key stakeholders including Kuaishou and respondents in both countries on how to overcome digital challenges and seize the opportunities presented by new digital models and technologies in developing countries.

Digital infrastructure at the BoP

The digital economy has witnessed the increasing importance of information as a factor of production in the development of economic and social solutions. However, information poverty and inequality are manifesting in the digital economy. The case of Kuaishou in China showed that the infrastructure at the Base of the Pyramid (BoP), in terms of short videos got popularised.

The accessibility of 4G networks and Wi-Fi availability, leading to value creation facilitated the Kuaishou business model at the BoP. The provision of information infrastructure in poor areas, therefore, has a direct impact on alleviating poverty. By doing so, the poor can access the internet through mobile communication services such as mobile phones. This has the potential to inspire the marginalised people to innovate and create business opportunities.

Education and training for information output

Information poverty is manifested in many ways; on the one hand, poor people cannot access and obtain high-quality information on production, consumption, and entertainment while on the other hand, they are unable to actively produce and transmit information. In the case of Kuaishou, it is the digital technology business model that helps to lower the threshold of information creation and output, thus providing the poor with the ability to express themselves. However, the low education levels of the poor impede this progress. The provision of free skills training in terms of graphic creation, video shooting, new media, and e-commerce, etc., can empower the marginalised people to fully use digital technology business models for value creation.

Local content based value creation

The Chinese Taobao village model focuses on the development of local industrial clusters driven by the connection between people and communities. Kuaishou's business model, on the other hand, focuses first on using content creation to establish the connection between people and content; then establishing person to person connection and finally superimposing the connection between people at BOP and local resources, which stimulates the value creation at BOP. However, the prerequisite for using this model to drive the poor out of poverty is to rely on the local value creation to support the realization of the market potential of local resources. The training, skills development and usage of local resource enhances the endowment at BoP. Once the content is disseminated and gathers significant attention, local governments monitor and transform it into economic and social programmes, thereby forming a sustainable loop. Active partnerships with private sector (MNEs) and grassroots entrepreneurs will further promote inclusive development.

Content-based business entrepreneurship at the BoP

Internet based entrepreneurship, as a new form of business model, faces few resource constraints and relies more on human resources. The innovative practice of short video apps has opened new ways for creating new meaning for 'daily life' that is different from traditional national imagery. It is particularly important during the COVID-19 pandemic and the lockdown, as a new communication and business model through online networking and meaningful exchanges. The IDMODEL project in collaboration with its partners has developed a digital technology-based business model and an App, 'Haate Haat', for value creation among the marginalised communities. This highlights the importance of community participation in value creation, opportunity recognition, and the development of capabilities (bottomsup approach). Special policies to support these initiatives, in terms of capital and technology, and facilitating the growth of grassroots entrepreneurs are required. Finally, there is a need for NGOs or other social organisations to facilitate the relationship between sellers, distributors, buyers, and service providers without charging any commission or fee.

Reflection

The findings of this pioneering research have so far provided insightful policy implications for technology-based business models in developing countries. The accessibility and affordability of technology, however, warrant further actions from local and national governments, local NGOs, and multinational enterprises (MNEs). This poverty alleviating policy action can only be achieved through effective collaborations between business, society, and politics.

Harnessing Ghana youth innovation potential for the SDGs

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Abstract

The youth constitute a significant and important demography of the world population. Particularly in Africa, almost 60% of the population is under the age of 25. It is important that this demographic dividend is harnessed. As the active participation of the youth in development is crucial in achieving sustainable and inclusive communities by 2030. As a demography born in the "knowledge society", which has brought about several tools and technologies they are strategically positioned to provide alternative solutions to our developmental challenge. For innovation to thrive, it requires actors in the innovation ecosystem play their respective roles. This paper seeks to assess the extent to which Ghana is harnessing the innovation potential of the Ghanaian youth for the attainment of the SDGs.

To this objective data a qualitative research design was employed. Data was collected from both primary and secondary sources. Government and private sector youth focused policies and intervention were reviewed. A round table of innovation ecosystem experts was organized to gather in-depth insights as well.

The study identified that most of the activities of ecosystem actors is centered on training. Moreover, the ecosystem is fragmented with not enough collaboration among actors. Little has been done in other areas to strengthen the ecosystem. The study recommends that future innovation-focused policies should highlight specific sections that detail the crucial role of the youth in its implementation. The legal and regulatory framework on business registration should be digitized. Our education curriculum which is critical to develop creative and problem-solving innovators must be reformed. Furthermore, new sources of finance should be unlocked for innovation as well implementing policies that incentive individuals and private institutions to invest in innovation. Again, investment must be made to build sustainable infrastructures particularly the digital infrastructure. Finally, more platforms should be created to foster industry-academia collaborations.

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Background

The 2030 Agenda, adopted at the United Nations Sustainable Development Summit in September 2015, positioned Science, Technology and Innovation (STI) as key means of implementation of the SDGs, and launched the UN Technology Facilitation Mechanism (TFM). The Annual Multi-Stakeholder Forum for Science, Technology and Innovation (STI Forum), supported by the Inter-Agency Task Team on Science, Technology and Innovation for the SDGs (IATT), has been the main fora for TFM to discuss topics of common interests of Member States and STI stakeholders in the context of the 2030 Agenda.

STI roadmaps and action plans to help realize the SDGs have been among the central topics through the first three STI Forums. In the Addis Ababa Action Agenda, Member States had committed to "adopt science, technology and innovation strategies as integral elements of our national sustainable development strategies" (para 119). In the 2017 STI Forum, participants highlighted that the STI roadmaps and action plans are needed at the subnational, national and global levels, and should include measures for tracking progress. These roadmaps incorporate processes that require feedback loops, evaluate what is working and not working, and produce continual revisions that create a real learning environment.

There is important knowledge and experience scattered across the 43 IATT members and other stakeholders. Therefore, this initiative is expected to add value through facilitating a common approach and developing a coherent framework to examine gaps, synergies and trade-offs, prioritize actions, strengthen national STI systems, and promote cross-sectoral collaborations and Goal-specific "deep dives" for the SDGs.

Methodology

To achieve the objective of this study, qualitative research design was employed. This involved collecting and analyzing non-numerical data to understand concepts or experiences in order to gather in-depth insights into the problem. Data collected were from primary and secondary sources. A sample of government policies and interventions as well as private sector inventions were reviewed and analyzed. Peer-reviewed literature on policies that spurred youth-led innovations were further analyzed. Finally, actors in the innovation ecosystem were interviewed on their experiences.

Policies and initiatives that harnesses youth-led innovations in Ghana

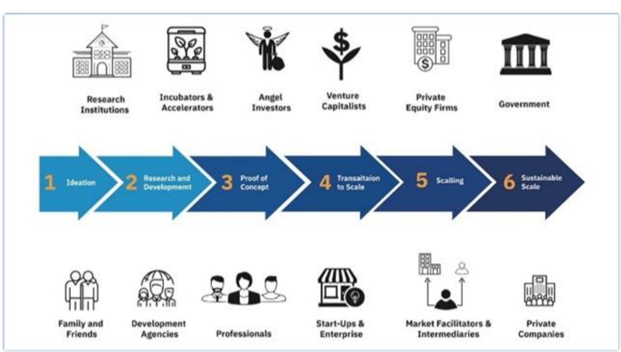
Findings

The findings have been framed in the context of the various components of an innovation ecosystem to provide some insight into ongoing activities as well as highlighting the strengths, weaknesses, opportunities and challenges.

Ghana's National Innovation Ecosystem

"It takes a village to raise a child, and it takes an ecosystem to scale innovation." The innovation ecosystem is defined by the British economist Christopher Freeman as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies. Nurturing and scaling innovation, requires the support of a robust innovation ecosystem. The influence of the national education system, industrial relations, technical and scientific institutions, government policies, cultural traditions, private sector institutions and many other national institutions is fundamental to harness youth-led innovation. This section seeks to discuss the components of the innovation ecosystem in Ghana and how they spur innovation.

Figure 1: ***Components of innovative ecosystem***



Government

The government/ public sector is a major player in the innovation ecosystem. The public sector has the responsibility of creating an environment that ignites innovation and supports entrepreneurs. There are ideally two approaches governments across the globe employ in the ecosystem namely the top-down and the bottom-up approach. With the top-down approach, the government acts as a planner and directly involves itself in the innovation ecosystem such as building incubators and technology parks, providing subsidies in research and promoting technology commercialization. On the other spectrum i.e., bottom-up, governments act as a facilitator and promote innovation through market mechanisms such as indirect incentives. Both approaches have their merits and demerits, as such some governments use a hybrid approach. From the interventions of the successive governments, it can be concluded that the state plays a hybrid role in the innovation ecosystem. Some of the broad-based policy directives to support the youth and promote innovation are detailed below.

National Youth Policy

The National Youth Policy was promulgated in 2010. Themed "Towards an empowered youth, impacting positively on national development". It is intended to provide guidelines for all stakeholders involved in the implementation of policies, programmes and projects for the development of the youth. The implementation plan of the policy was launched in 2015 and highlights specific interventions in the areas of human development and technology; economic empowerment; youth participation in governance; youth leadership; and sports and national orientation. To practicalize the agenda of the policy, necessary steps have been taken to restructure the curriculum of Youth Leadership and Skills Training Institutes and to align it with the competency-based approach within the Council for Technical and Vocational Educational Training framework for the formal sector skills training development (NDPC, 2017: 212).

National Science and Technology Innovation Policy (STI)

The STI Policy is the primary document guiding Ghana's efforts to mainstream Science, Technology and Innovation in its pursuit of development. More specifically, Ghana's vision is to develop to become a high–income country which fully applies and integrates STI into national development strategies (MESTI, 2017: 24). The policy highlights programmes and activities in selected sectors which can be driven by application of STI. One of the key focus areas is youth innovation. Some specific interventions to be implemented to harness youth innovation include promoting innovation at all levels of the educational system, providing scholarships to promising science students, initiating mechanisms to identify and mentor early identify young talented scientists and establishing award schemes that reward innovation from the youth.

National Entrepreneurship & Innovation Plan (NEIP)

NEIP is a policy initiative with the primary objective of providing an integrated, national support for start-ups and small businesses, focusing on the provision of business development services, business incubators, and funding for youth-owned businesses. NEIP is a special purpose vehicle launched in 2018 by the President H.E Nana Akufo Addo to stimulate entrepreneurship and job creation. The government seeded the program with $10m. The policy is focused on the following: access to business advisory services, training and incubation, access to funding, access to markets and policy formulation to create an enabling environment. The targeted sectors include agribusiness and agro processing, ICT, sports, tourism and creative arts, health, sanitation and waste management, transport and logistics, fashion and beauty, manufacturing and industrial processing.

Other initiatives under the NEIP are the Presidential Pitch, School Entrepreneurship Initiative (SEI), Greenhouse Estates Project and Youth in Industry. The Presidential Pitch provides financial support to entrepreneurs under 35 years who are in the ideation stage of business. In 2019, the winner of the pitch competition was a team of two females of Kwame Nkrumah University of Science and Technology who process sanitary pads using plantain and banana fibre. SEI inculcates entrepreneurship mindsets among students through the creation of student clubs in secondary schools. The Greenhouse project seeks to modernize vegetable production and produce import-substituted goods and solve the problem of food security. The last initiative, Youth in Industry's goal is to build a sub-contracting industry to feed the larger industries. The various initiatives will be the springboard to stoke creativity in young people.

Nation Builders Corps (NABCo)

To tackle the challenge of unemployment and provide decent jobs to the youth, the government introduced the National Builders Corps. The program places unemployed graduates in both the public and private sector to enable them to develop skills for the workplace. The debut recruitment engaged 100,000 graduates who are placed in seven modules namely Educate Ghana, Heal Ghana, Feed Ghana, Revenue Ghana, Digitize Ghana, Civic Ghana and Enterprise Ghana.

Education

The educational institutions represent another crucial actor in the innovation ecosystem. These institutions play three key roles and are important due to their knowledge generation, impartation and diffusion roles they play. First, educational institutions are responsible for feeding the ecosystem with the raw materials i.e. human resources. Secondly, through their research activities, they play a role in discovering and inventing for the future and various ground-breaking solutions have been generated by such institutions. An example of this would be The Council for Scientific and Industrial Research, Ghana (CSIR) who are continuously researching and introducing several disease-resistant seeds to the market for farmers in Ghana. Finally, these institutions transfer knowledge to industry. While the universities produce the knowledge, industries implement it. For instance, the CSIR's egg powder innovation has been commercialized by entrepreneurs into marketable products.

Free Senior High School Policy

The policy seeks to eliminate the cost barrier and create an equal playing field for Ghana's youth to access education to the secondary school level. In the words of the President of the 69th Session of the United Nations General Assembly, H.E Sam K. Kutesa, "the more young people grow into well-educated adults with fewer dependents and new opportunities to acquire wealth, savings and purchasing power, the more they will be able to accelerate economic growth and development". The policy will produce a pipeline of skilled youth for the industry. As a result of the policy, the enrolment in 2018 (490,882) represented an increase of 36% over the 2017 enrolment (361,771).

Incubators and Accelerators

The third component of the innovation ecosystem is the business incubators, accelerators and entrepreneurial support organizations. These organizations are "designed to accelerate the growth and success of entrepreneurial companies through an array of business support resources and services that could include physical space, capital, coaching, common services, and networking connections." Incubators provide a "safe space" for entrepreneurs to test and validate their ideas before they enter the market. An incubator such as MEST Ghana, provides individuals with software and entrepreneurial training. Through these initiatives, innovators and entrepreneurs are able to identify several landmines which could have cut short their entrepreneurial life. Accelerators in addition to the education, mentoring and networking often provide financial investment as well. Limited data exists on the impact of incubators/ accelerators in Ghana. However, findings from the Acceleration in Sub-Saharan Africa report points to the fact that direct funding, network and business skills were the main benefits entrepreneurs received from the sampled entrepreneurs. Research also shows that attending an accelerator is positively associated with three outcomes measures: survival, employee growth, and funds raised.

Public/Private Sector interventions

Ghana Tech Lab

The Ministry of Communications under their eTransform project has implemented ICT projects to promote digital entrepreneurship and create digital jobs. With support from the Ministry and World Bank, the Ghana Tech Lab project is being implemented by Kumasi Hive and Innohub which are both private institutions with demonstrated experience in incubating and accelerating youth innovation in the country. The lab harnesses youth innovation by providing prototype testing labs, maker and creative spaces, robotics and artificial intelligence labs and coworking spaces. As part of its programs, the lab trains young people in web and application development.

Ghana Innovation Hub

Ghana Innovation Hub is another project under the eTransform project of the Ministry of Communications. The hub was set up by a consortium made up of BlueSpace Africa, the Ghana Technology University College and MDF West Africa. These private organizations support youth innovations by providing business development, investor matchmaking services among others. The hub also hosts other initiatives like the Orange Corners of the Netherlands Embassy which is also designed to support early-stage businesses.

Ghana-Oracle Digital Enterprise Program (GODEP)

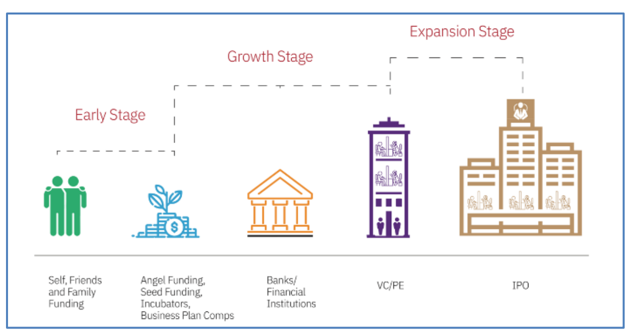
GODEP is an initiative launched in 2019 by the government of Ghana and implemented by the Accra Digital Centre in partnership with Oracle's Global Startup Ecosystem. An acceleration program which provides startups with modern business resources and technologies. GODEP aims to accelerate 500 local startups. The program accelerates startups in the areas of agritech, cybersecurity, digital health, industry 4.0, fintech, watertech. Selected startups go through a 3-month incubation period where they are exposed to modules in designing, developing and deploying their technologies. Participants are awarded access to oracle's ecosystem, experts, hands-on workshop on cloud technology, mentorship and advisory, networking opportunities and publicity.

The first two startups (Health Direct Global and Techshelta) selected to join the program have gone on to win international awards. Techshelta which builds internet-of-things devices to enable greenhouse farmers to remotely control their operations won the 2019 African Green Revolution Forum Pitch AgriHack competition. Health Direct Global, a healthtech startup which leverages on artificial intelligence to build electronic health records which match users to health providers in real-time and also provide alternative health financing for people at the bottom of the pyramid won the PwC Japan Prize for Business Model, Innovation and Scalability at the Japan/Africa Pitch Competition held during the 2019 Tokyo International Conference on African Development Forum.

Finance

Access to finance, the fourth pillar also plays a critical role in the innovation ecosystem. Finance enables organizations to conduct research, adopt technologies necessary for inventions as well as develop and commercialize innovations. The different stages of innovation require different types of financial support. The image below illustrations this.

Figure 2. *Stages of innovation and financial support required for each step*



Source: Adioma

Angel Investors are high net worth individuals who provide financial support in exchange for equity. They are normally the first external option for start-ups because of their high tolerance for risk. These financiers come in quite early in the life cycle of a business. Apart from providing money, they provide entrepreneurs with mentorship and access to their network. At the early stage (i.e. ideation or proof-of-concept), angel investors are instrumental in the innovation ecosystem because they spur innovation through financing, as well as "de-risking" innovation at the early stage for future investment. The Accra Angels Network has been established to play this role. Similar to angel investors, venture capital firms (VCs) also provide capital to early or growth stage companies. Unlike angels who often operate informally. In developed economies, banks often step in to provide capital to start-ups and Small Medium Enterprises (SME). In emerging markets, however, commercial banks tend to shy away from lending to startups and SMEs, as it is risky and costly. Although, in Ghana, some banks have developed products for SMEs this has not yet been extended to start-ups.

n summary, the entrepreneurial finance ecosystem i.e., angels, venture capital and banks are instrumental in the development of the innovation landscape. In Ghana the entrepreneurial finance ecosystem is in its nascent stages with capital flow for innovation generated mainly from foreign investors. Policies must be implemented to incentivize local high net worth individuals and financial institutions to support innovation in the country.

Tax Amendment Act

To stimulate entrepreneurship and innovation, the government in 2018, amended the income tax act to provide tax relief for young entrepreneurs under the age of 35. Government through the National Entrepreneurship and Innovation Plan grants tax holidays to startups. The policy exempts the income of businesses in the manufacturing, information and communications technology, agro processing, energy production, waste processing, tourism and creative arts, horticulture and medicinal plants sectors from tax for a period of five years. Entrepreneurs are also entitled to carry forward any unrelieved loss for a period of five years. Furthermore, post the five years tax holidays, the business will also enjoy reduced tax rates based on their location. Businesses located in Accra and Tema will be taxed at 15%. Business located in other regional capitals outside the three Northern regions will be taxed at 12.5% while those located outside the other regional capitals will be taxed at 10%. Those located in the three Northern regions however, will be taxed at 5%. The empirical analysis suggests that the most effective way to increase innovation and productivity is through government tax subsidies and grants.

Venture Capital Trust Fund Act

The Venture Capital Trust Fund (VCTF) was established by Venture Capital Trust Fund ACT, 2004, (ACT 680) which aims "to provide financial resources for the development and promotion of venture capital financing for Small and Medium Enterprises (SMEs)". Since its creation in 2004 by the Venture Capital Trust Fund Act (Act 680), the VCTF has leveraged its seed funding to increase the pool of funds available for SME investing over US$40 million through the private partnership agreements.

Accra Angels Network

Accra Angels Network a private sector initiative that provides the platform for 'mid-to-high' net worth individuals or institutions to invest their funds and resources in Ghanaian based early-stage businesses, which have a significant growth potential. Besides investment, the network also provides training for both investors and entrepreneurs, mentorship and access to networks and markets.

Private Sector

Innovation typically sits within the private sector as they conduct research and development, drive knowledge-sharing networks, and investment in infrastructure. These activities catalyze, and increase innovation. Investment in telecommunication infrastructure over the years has facilitated the mobile money/ fintech revolution in Ghana.

Furthermore, the private sector also provides platforms which nurture future innovations. Corporate hackathons such as the Ecobank Fintech Challenge provides entrepreneurs in fintech the opportunity to birth solutions using the bank as a sandbox. Moreover, the private sector are potential customers or acquirers of innovation. In developed countries, corporations are always on the search for acquisitions of innovative ideas.

In Ghana the private sector has begun to play an active role in the innovation ecosystem. These activities and interventions undertaken by corporates now go beyond the idea of corporate social responsibility. Corporates now contribute to society from the perspective of shared value. Shared value is defined "as policies and practices that enhance the competitiveness of companies while improving social and environmental conditions in the regions where they operate". This business strategy focuses on creating economic benefit while identifying and solving social problems. For a program to be deemed as a shared value, there must be an identified economic benefit to the company as well as a measurable social or environmental impact. The concept of doing well while doing good is exhibited in these circumstances. In other words, corporates ensure that their bottom line is impacted as well as impacting the socio-economic environment they operate in.

Through corporate interventions, new solutions are provided, jobs are created, income is generated for individuals and governments, governments that are dedicated to the growth and development of efficient ecosystems should prioritize private sector/ corporate participation for accelerated results.

Stanbic Bank Ghana, offers a shared value program through their Stanbic Business Incubator. The program offers a safe space for youth innovation. Innovators and entrepreneurs through the incubator have the opportunity to test their ideas and get the needed support to scale. Although the bank is helping to solve societal problems through this initiative, it also contributes to its growth strategy. This is key considering an initiative as a shared value. The incubator provides the bank with a pipeline of future customers and innovative business models it can tap into.

The Kosmos Innovation Center (KIC), an intervention of Kosmos Energy Ltd.was established in 2016 to tackle the numerous challenges in the agriculture sector. According to the Chairman and CEO, Andy Inglis "it's in our company culture to tackle tough challenges, so we decided to grapple with the issues facing agriculture – Ghana's most important sector and largest employer". Through this intervention, 500 budding entrepreneurs have been trained and 19 startups have been launched out of which 14 have joined the incubator program. KIC has facilitated over $300m in seed funding for the startups which has led to the creation of more than 200 new jobs.

Another important sub-component of the private sector is the media. The media educates, informs, persuades and entertains the public. In the innovation ecosystem, the media helps to put a spotlight on innovation. Furthermore, private sector plays a role in advocacy, engaging government and policy makers through the vehicle of networks and associations.

The 'Joy Business Van' – an entrepreneurship-focused series by Joy TV seeks to give Small and Medium Scale enterprises and start-ups visibility to attract potential markets. The show also highlights their issues and challenges. Similarly, Citi FM's Citi Trends host Ghana's bright talents in the technology ecosystem on conversations on technology solutions in an emerging market as Ghana. Ashesi University's Y Campus Express Radio also runs programs that are aimed are sensitizing the students and the general public on the concept of entrepreneurship.

Another actor to be discussed in the innovation ecosystem are the civil society organizations. According to the World Bank, civil society includes "the wide array of non-governmental and not-for-profit organizations, labour unions, indigenous groups, charitable organizations, faith-based organizations, professional associations, and foundations." These organizations play several roles in the ecosystem. Economic development focused foundations support new and creative solutions to end persistent global problems. They implement their goals by providing diverse support to innovators. Other civil society organizations are also involved in lobbying, monitoring and policy advocacy and are often advocating for changes in the innovation ecosystem.

The final actor under lens are the development agencies. Development agencies being an actor, are usually governmental agencies which support development. Development agencies seek to find alternate routes to social and economic development in developing countries. In that vein, they support the innovation ecosystem by providing blended finance instruments to de-risk early-stage innovations as well as providing ecosystem building support. In 2019, the French Development Agency through their Chose Africa agenda dedicated 2.5 billion euros to support African entrepreneurs by 2022. The German Development Agency (GIZ) Ghana, through its "Digital skills for entrepreneurial women" project, provides digital skills for women. Development agencies provide key support for economic development in developing countries however more work needs to be done to ensure alignment between their objectives and the host country.

There are also sector specific policies to encourage youth participation namely agriculture and financial technology. The agriculture sector is the largest employer in Ghana however this is not reflective in the contribution to GDP. The government is therefore encouraging youth participation and innovation in this sector. The policies listed below are a reflection of this.

Youth in Agriculture Programme

The Youth in Agriculture Programme (YIAP) is a Government of Ghana (GOG) agricultural sector initiative with an objective of motivating the youth to accept and appreciate farming/food production as a commercial venture, thereby taking up farming as a lifetime vocation. The YIAP has the task and responsibility of mobilizing the youth to take up farming and its other related activities as a lifetime vocation. By so doing the following benefits will be derived from the employment for the youth, through the provision of tractor services and agro-inputs;

In advance economies, governments' policies help spur commercial innovation and governments invest heavily in research and development. Research is often commercialized which can lead to innovative products and services which drive economic growth. In comparison in developing economies, governments lack the financial and human resources to do so. Governments encourage private sector participation to fill the necessary gaps however policies and incentives are yet to be developed to catalyse this.

Rural Enterprises Programme ENABLE Youth 1 District 1 Factory Initiative

The Rural Enterprises Programme is funded by the Government of Ghana, African Development Bank and the International Fund for Agricultural Development. The project seeks to reduce poverty and improve living conditions in rural areas by improving technology and skills needed for private sector development. A sub-component of the project is the Enable Youth initiative which seeks to encourage young graduates to own and manage agro-processing factories in selected districts across the country. To ensure sustainability, Enable Youth 1D1F adopts a continuum of value chain approaches in ensuring that young entrepreneurs own and manage Strategic Business Units (SBUs) representing major operations entry points of the factories. Enable Youth will provide holistic support to entrepreneurs by offering a comprehensive and integrated package of training in agribusiness, financing, continuous mentorship and partnership with the private sector, business and professional associations. According to the Minister of Finance, 58 small processing factories are expected to be set up in 2020.

Digital Finance Policy

Advancement in technology and improved internet connectivity has led to a new era of digital financial services in Ghana disrupting the business models of traditional financial institutions. Financial technology has accelerated financial inclusion providing access to financial services to the unbanked. With a budding digital finance infrastructure, the government through the policy seeks to build on the gains made to create a resilient, inclusive and innovative DFS ecosystem that contributes to social and economic development. The policy identifies six areas for action; governance, enabling regulation, capacity building, market infrastructure, digital payment use cases and support for fintech. As part of the short-term action plan, the government is expected to provide direct support for fintech entrepreneurship. Through the National Entrepreneurship and Innovation Plan, specific innovation hubs that support young fintech entrepreneurs will be developed. These hubs are the platform which provides entrepreneurs with business development services, access to finance and mentorship opportunities. Furthermore, the government is expected to promote tech and entrepreneurship-focused curricula in universities and technical schools to help groom the next generation of fintech entrepreneurs. The policy has the potential to spur youth-led innovation and access to finance will contribute to the decent work and economic growth of the people.

Policy recommendations

Strategies to enhance the critical contributions of STI and the role of the youth and private sector in achieving the SDGs.

From the sample of policies reviewed that were targeted at promoting innovation, the following had a specific reference to youth involvement (Science Technology and Innovation Policy (2017), Income Tax (Amendment) Act, (2017), Free Senior High Policy, Digital Finance Policy (2019) and the National Youth Policy (2019)). We recommend that policy development should take a more collaborative approach and increase the level of youth consideration and engagement particularly in light of the demographics of the population and the predicted demographics by 2030.

The legal and regulatory processes could to be simplified to encourage youth to participate in the economy at a formal level also allowing for better data collection. Digitalizing processes will encourage more youth to formalize their businesses and seek the correct licensing for their innovations. The entire process can be simplified by moving applications online, some work is ongoing in this area which is being led by the Vice Presidents digital transformation unit.

The intellectual property (IP) system in the country needs to be strengthened and could also benefit from a digital transformation. Additional funding should be channeled to the enforcers of IP rights (i.e., Customs Excise and Preventive Service, the Police Service and the Judiciary) to allow them to operate effectively. On the continental front, the two regional IP frameworks i.e., the African Regional Intellectual Property Organization and the Organization Africaine de la Propriété Intellectuelle which guarantees IP rights for Anglophone and Francophone countries respectively need to be linked. In its current state, patents issued under the Anglophone framework are not recognized under the Francophone framework and vice versa. A unified framework, provides innovators with the assurance that they are protected particularly in light of the onset of the Africa Free Trade Area.

The importance of human capital development cannot be overlooked. Although the government has implemented the Free SHS policy a bold and necessary step in the right direction. African youth need to receive an education that is relevant and is directed towards developing the skills needed to be productive adults. School curricula must be reviewed to suit global standards. Public education institutions lack the requisite tools and equipment needed to enhance the teaching and learning of science and technology. Local innovators are attempting to solve for some of these challenges. This presents an opportunity for collaboration between government, private sector and innovators strengthening several components of the ecosystem.

The anticipated NEIP Fund could act as a catalyst for investors to participate in the venture capital asset class. In addition, policies must be instituted to stimulate participation and encourage angel investment. The minimum capital requirement of $200,000 for joint venture investments must be re-evaluated. Early-stage entrepreneurs typically raise funding from angel investors who invest approximately $10-50,000, the $200,000 threshold is therefore a deterrent. There are several examples of best practice across the continent as well as globally and the Africa Venture Capital Association in addition to the Africa Business Angels Network are available to provide support to local actors.

Studies show that reducing the price of R&D by 10% increases investment in innovation by 10% in the long run. Interventions such as the Kosmos Innovation Center and SB Incubator as well as technology hubs and innovation centers across the country could be included in the tax incentive regime. The President's pledge of ensuring that at least 1% of Ghana's GDP goes towards research and development, and subsequently increased to at least 3% overtime presents an opportunity to aggregate and channel the necessary funding toward the ecosystem. In South Africa 2.5% of corporate tax is allocated to innovation parks to support the development of the local ecosystem. Also, the establishment of the National Research Fund will stimulate interest in research and development at the tertiary institutions level.

Furthermore, the construction of sustainable infrastructure such as roads, electricity and communication networks are key for development. A thriving digital sector requires adequate digital infrastructure, technology-literate end-users, technology talent with an entrepreneurial spirit, and a friendly business environment. Although mobile penetration in Ghana is estimated at 130% of the population, however, internet penetration is as low as 48%. Investment in digital infrastructure should be prioritized.

Academia-industry collaboration is critical, currently, both industries are disconnected with limited collaboration. The basic function of universities is to create knowledge through research, to act as long-term guardians of this knowledge and to transmit it to others through education. Industries on the hand practicalize the theories produced in universities. An academia-industry collaboration is a win-win situation for both parties. Universities will have the opportunity to test the practical application of their research, access funds for academic research, gain insights on research, further the universities outreach mission and look for a business opportunity. Industries will have the opportunity to solve specific technical or design problems, develop new products and processes, conduct research leading to new patents, improve product quality, reorient R&D agenda and have access to new research via seminars and workshops.

Finally, the implementation of policies and the monitoring and evaluation of projects and initiatives should remain a priority. The recent establishment of the Ministry of Planning and the Ministry of Monitoring and Evaluation could be considered best practice if they are able to combine efforts and work together to ensure that there is first cohesion across policies and second joint efforts toward implementation.

Conclusion

Although Ghana's ecosystem is in nascent stages, there has been rapid development over the last 10 years. With an intentional strategy the next 10 years could see Ghana positioning themselves as one of the most vibrant ecosystems on the continent. The decade of action could be used as an opportunity to develop partnerships across the continent and globally to harness best practice for accelerated growth. Ghana has laid a strong foundation however it appears that there isn't a specific objective or a target in place in relation to the innovation ecosystem or contributions towards the attainment of the SDGs.

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G. Findings and recommendations from selected UN flagship publications

Overview

Ten inputs were considered based on relevant UN publications, with diverse coverage of specific frontier technologies. They look at rapid technology change using different frames of analysis. They include UNIDO's Industrial Development Report 2020: Industrializing in the Digital Age, ILO's World Employment and Social Outlook 2021: The role of digital labour platforms in transforming the world of work, UNCTAD's "*Technology Innovation Report 2021: Catching technological waves: Innovation with Equity*", ITU/UNESCO *Broadband Commission for Sustainable Development's State of Broadband Report 2020* and ESCWA's *Big Data for Good: Can Big Data Illustrate the Challenges Facing Syrian Refugees in Lebanon?*

UNIDO's *Industrial Development Report 2020* looked at a specific group of frontier technologies called "Advanced Digital Production" technologies, including robots, 3D printing, bid data analytics, cloud computing and artificial intelligence. ILO's *World Employment and Social Outlook 2021* looked at the effects of digital labour platforms on workers and firms. UNCTAD's *Technology Innovation Report 2021* looked at 11 frontier technologies (AI, Internet of things, big data, blockchain, 5G, 3D printing, robotics, drones, gene editing, nanotechnology and solar PV) from the broad frames of inequality and development, ITU/UNESCO *Broadband Commission for Sustainable Development's State of Broadband Report 2020* looked at broadband Internet and ESCWA's Big Data for Good looked at the specific issue of big data analytics using non-traditional data sources.

Most of the reports provide an analysis of the impacts of frontier technologies and make recommendations, although not all make recommendations. The focus on some specific frontier technologies is one of the few common points of all the reports, although most of them cover their impacts on sustainable development along some dimensions. Those dimensions range from narrow to very broad in focus. The most common points of commonality in terms of impacts include those on workers, employment and jobs, gender, efficiency and productivity. UNIDO and UNCTAD reports include analysis of impacts on production, innovation and industrial development. UNCTAD's report also includes an analysis of the multifaceted impacts on inequality from a broad range of frontier technologies.

There is broad agreement among most of the reports that the frontier technologies driving rapid technology change are creating deep economic, social and environmental impacts which could be long lasting and disadvantage those communities, workers, firms, sectors and countries that do not have the infrastructure, skills and access to the technologies needed to be able to benefit from them. They also agree that the global community can - and should - take actions to moderate the negative impacts on workers and jobs, and the natural tendency of the uneven diffusion of these technologies across firms, sectors, communities and countries to create large technology and development divides both across and within countries. There are strong grounds for policy intervention to combat these naturally occurring tendencies that could leave many people, communities and countries behind in terms of improving the lives of people everywhere.

Table 1. *Summary of findings and proposed actions in recent UN publications*

Theme	Findings	Proposed actions
Advanced digital production (ADP) technologies	They have been adopted by a small number of firms in selected sectors in a relatively small number of countries, but diffusion continues. Those firms using them have increased productive efficiency, which can be environmentally beneficial by using fewer material inputs. Their effects depend partly on the mix of process versus product innovation effects. Patents and production of these technologies are dominated by a few economies. A larger number of developing and emerging economies adopt them via the import of capital goods in which they are embodied.	Specific recommendations were not included. But recommendations were made by other UN reports for policy action of different sorts to prevent extreme gaps in access and spread benefits more widely.
Digital labour platforms	The platform business model is transforming the world of work. Platforms have created a dual labour market with a core small workforce of internal employees and a large external mediated workforce that executes the tasks. The working conditions on digital labour platforms are largely regulated by terms of service agreements, which has implications on working conditions. Workers on digital labour platforms often struggle to find sufficient well-paid work to earn a decent income, creating a danger of working poverty. Many do not have access to social protection.	• Ensure workers' employment status is correctly classified and is in accordance with national classification systems. • Ensuring transparency and accountability of algorithms for workers and businesses. • Ensure that self-employed platform workers enjoy the right to bargain collectively. • Ensure all workers, including platform workers, have access to adequate social security benefits, through the extension and adaptation of policy and legal frameworks where necessary. • Provide for wage protection, fair payments and working time standards.
Frontier technologies and widening multifaceted inequalities	Rapid technology change offers great benefits but is also opening new dimensions of technology gaps across and within countries and can exacerbate inequalities along many multifaceted dimensions. Frontier technologies are being used to provide services via digital platforms that have spurred the creation of a 'gig economy'. The gig economy provides employment, typically on insecure terms. Biases within AI systems can arise in a number of ways, either because they employ biased algorithms, or they use biased data for training. Artificial agents learning from human-derived data will often learn human biases, both good and bad. Both companies and regulators need to be vigilant to ensure that technologies using AI do not incorporate or learn social biases and forms of discrimination that can further disadvantage vulnerable groups.	• Use public policy to guide innovation in new and emerging technologies so as to support sustainable development. • Developing countries should deliberately adapt and use automation to increase productivity, promote economic diversification and create jobs • Calibrate digital policies according to the country's readiness to engage and benefit from the digital economy. • Ensure country-wide access to electricity and ICTs, aiming to bridge gender, generational and digital divides, focusing on those furthest behind. • Strengthen social protection systems to provide safety nets for workers who may lose their livelihoods. • Ensure people can acquire the necessary digital skills and competencies to adopt and adapt frontier technologies into countries' existing production bases. • Enable workers to move to new jobs and economic activities by matching their skills to future needs, reforming education, and training systems, and promoting lifelong learning.

		• Facilitate dialogue between workers and employers. • Explore ways to make goods and services that use frontier technologies benefit vulnerable and low-income groups. • Ensure that technologies using AI do not incorporate or learn social biases and forms of discrimination that can further disadvantage vulnerable groups. • Establish appropriate governance frameworks.
Frontier technologies widening gender inequality	New technologies pose particular challenges to women, given their underrepresentation in STEM fields and the persistent gender gap in access to, and use of, digital technologies. Technological change is also shaped by gender inequalities. Because of the uneven gender balance for occupations, women and men will be affected differently by job impacts. The gig economy may also increase gender inequality. AI can also perpetuate stereotypes and reduce the benefit of products for women.	• Improve understanding of the gender impacts of technological change. • Facilitate women's access to technology, ensuring that they participate in setting priorities, shaping policy decisions and creating research and development agendas. • Encourage girls and women to study and seek employment in science, technology, engineering and mathematics (STEM) fields, which have driven the rapid development of frontier technologies.
Improving broadband Internet access	COVID-19 has demonstrated the centrality of connectivity as many adults and children have shifted towards remote work, learning, and communication. It has demonstrated the need to accelerate digitization of economies in ways that are inclusive of all people, everywhere. But many are still left behind with little or no access. There is an urgent need for creating enabling policy and regulatory frameworks that can play a facilitating role, including through the government policies needed to prioritize broadband as part of basic infrastructure.	• Make broadband policy universal, a funded national broadband plan or strategy in all countries by 2025. • Make broadband affordable, especially in developing countries, by 2025. • Get people online, with specific global, developing country and LDC targets to reach by 2025. • Build digital skills and literacy, with 60 per cent of youth and adults achieving at least a minimum level of proficiency in sustainable digital skills by 2025. • Provide digital financial services, with 40 per cent of the world's population using digital financial services by 2025. • Get businesses online, and improve connectedness of Micro-, Small- and Medium-sized Enterprises (MSMEs) by 50 per cent by 2025. • Achieve gender equality in all broadband access targets by 2025.
Harnessing big data analytics ethically	Timely and accurate statistics are a crucial element in the policy-making process for crisis responses, which necessitate accurate and near-immediate information to inform policy makers on the magnitude and extent of the threats and vulnerabilities. With bid data analytics, non-traditional data sources (such as mobile phone call detail records and databases) can be leveraged to offer valuable insights for policy makers, especially in crisis responses.	• Establish partnerships for accessing data and ensuring the appropriateness and soundness of research using such information sources, as well as upholding appropriate ethical standards.

Sources: Selected recent UN publications covering rapid technology change and frontier technologies.
Note: Selected findings and recommendations of UNCTAD's TIR 2021 are presented.

List of findings and recommendations

For ease of access, this section lists summary points on key findings and recommendations of the above-mentioned reports.

UNIDO's Industrial Development Report 2020 series of policy briefs

A series of highly readable policy briefs summarize the most important findings of UNIDO's Industrial Development Report 2021. Several of them relate directly to the themes in the present IATT report. Strictly speaking they focus on findings, not recommendations.

Policy Brief 1 From new technologies to industrial development… and back

New technologies unlock product and process innovations, leading to expansion of industries, the creation of job and income opportunities, and the greening of the economy. Producing and absorbing new technologies is therefore key to achieving ISID.

New technologies create jobs both directly and indirectly, extending the multiplier effect of industrial development outside factory boundaries.

New technologies can help launch environmental goods in the market and, by increasing the efficiency of production, make manufacturing less material- and energy-intensive.

Policy Brief 3 A new technological wave shaping industrialization: advanced digital production (ADP) technologies

The concept of the Fourth Industrial Revolution (4IR) is based on the growing convergence of emerging technology domains and their complementarity in production.

ADP technologies include the industrial internet of things (IoT), big data analytics, artificial intelligence and 3D printers for additive manufacturing.

ADP technologies have emerged from the engineering and operational principles of previous industrial revolutions. They are best understood as the result of a process of evolutionary transition rather than revolutionary disruption.

Policy Brief 4 The contribution of advanced digital production (ADP) technologies to inclusive and sustainable industrial development (ISID)

ADP technologies contribute to ISID by unlocking product innovations, which can address societal and environmental needs, and by improving manufacturing production's efficiency.

At the aggregate level, the diffusion of ADP technologies is associated with improvements in economic performance. Countries that actively engage in ADP technologies experience faster growth rates in manufacturing value added (MVA).

In developing and emerging industrial economies, the diffusion of ADP technologies is associated with positive employment trends at both the country and enterprise level.

Policy Brief 5 The diffusion of advanced digital production (ADP) technologies: a heterogeneous landscape

Patenting and exporting activities in the field of ADP technologies are confined to a handful of frontrunner economies. This group accounts for over 90 per cent of the world's patents and 70 per cent of the world's exports in ADP technologies.

ADP technologies remain the domain of a small niche of firms and industrial sectors, even in frontrunner economies.

Developing and emerging industrial economies are increasing their adoption of ADP technologies, chiefly through the import of capital goods—such as robots—which embody the new technologies.

Participation in global value chains (GVCs) is another important driver of technology diffusion in developing and emerging industrial economies.

Policy Brief 7 The contribution of ADP technologies to environmental sustainability

Improvements in production efficiency in manufacturing effected by ADP technologies are associated with energy and material savings, as well as with lower CO_2 emissions.

Patents for goods fuelled by ADP technologies are significantly "greener" than the average patent.

Environmental goods increase our quality of life while minimizing our impact on the environment.

ILO's World Employment and Social Outlook 2021: The role of digital labour platforms in transforming the world of work

The report is a first major attempt by the ILO to capture the experiences of workers and businesses with digital labour platforms. It is based on surveys and interviews with workers, businesses, platform companies and platform worker associations around the world in multiple sectors and countries.

Key findings:

Digital labour platforms offer new markets and innovative ways of outsourcing work for businesses, as it enables them to use these platforms to access a global and local workforce to improve efficiency and productivity.

The platform business model is transforming the world of work in a number of ways. It allows platforms to organize work without having to invest in capital assets. It shifts the responsibility of investing in capital assets to the workers, be it cars for taxi drivers or computers for online web-based workers, including the operating costs such as fuel, internet or electricity.

Platforms have created a dual labour market with a core small workforce of internal employees and a large external mediated workforce that executes the tasks. They mediate between the workers who perform the tasks and clients and manage the entire work process such as allocation of work, evaluation and monitoring and reward of work through algorithmic management practices.

The working conditions on digital labour platforms are largely regulated by terms of service agreements, which has implications on working conditions.

Platforms use algorithms to match workers with clients or customers, a process in which worker ratings are key and decisive and also an important performance management tool. The ratings are themselves algorithmically determined, according to a number of metrics, which in effect limits workers' ability and freedom to reject work.

Workers on digital labour platforms often struggle to find sufficient well-paid work to earn a decent income, creating a danger of working poverty. Many do not have access to social protection.

To address the challenges faced by this new way of working, many governments have taken regulatory initiatives to tackle issues such as the employment relationship, health and safety standards and adequate social protection. There have been diverse practices of regulation of platform workers across the world.

Some initiatives have also been taken by private, non-state actors, and employers' and workers' organizations. However, variations in these regulatory responses have created further challenges. The matter is made more complex because many digital labour platforms operate across multiple borders and jurisdictions. The result is regulatory uncertainty for workers, businesses and governments alike.

The report includes 15 recommendations about what needs to be done. Some of these include:

- ensuring workers' employment status is correctly classified and is in accordance with national classification systems.
- ensuring transparency and accountability of algorithms for workers and businesses.
- ensuring that self-employed platform workers enjoy the right to bargain collectively.
- ensuring all workers, including platform workers, have access to adequate social security benefits, through the extension and adaptation of policy and legal frameworks where necessary.
- providing for wage protection, fair payments and working time standards.

UNCTAD's Technology Innovation Report 2021,

Selected findings of this UN report entitled "Catching technological waves: innovation with equity" include the following:

Frontier technologies are being used to provide services via digital platforms that have spurred the creation of a 'gig economy'. The gig economy provides employment, typically on insecure terms, creating a precarious class of dependent contractors and on-demand workers. The consequences for inequality will depend on whether the gig workers are poor people who would otherwise be unemployed, or middle-class people looking for small additional incomes.

Frontier technologies are expected to become cheaper and easier to access and use. Some of the most important developments have been in energy. The cost of solar panels has fallen by a factor of more than 100 over the last 40 years, and by 75 per cent over the past 10 years. Over the coming years, there are likely to be further breakthroughs in the design and manufacture of photovoltaic cells and battery storage systems, with possibly the advent, in the not-too-distant future, of printed organic solar cells.

New technologies pose particular challenges to women, given their underrepresentation in STEM fields and the persistent gender gap in access to, and use of, digital technologies. Technological change is also shaped by gender inequalities. This is partly because men have been more likely than women to study STEM subjects and have STEM careers.

The gig economy may also increase gender inequality.

AI can also perpetuate stereotypes and reduce the benefit of products for women.

Biases within AI systems can arise in a number of ways, either because they employ biased algorithms or they use biased data for training. Efforts may be made to hide sensitive fields from algorithms, such as those on race and gender. But learning algorithms can use probabilistic methods to recreate these fields and make discriminatory decisions. Artificial agents learning from human-derived data will often learn human biases, both good and bad. Both companies and regulators need to be vigilant to ensure that technologies using AI do not incorporate or learn social biases and forms of discrimination that can further disadvantage vulnerable groups.

One major concern is the impact on labour markets of AI and robotics combined with big data and IoT. Because of the uneven gender balance for occupations, women and men will be affected differently.

Many frontier technologies rely on steady, high-speed fixed Internet connections, such as fibre optic cable, or on high-speed mobile connections. In the case of broadband many developing countries do not have adequate digital infrastructure, and for most of their people Internet costs are prohibitive.

<u>Selected recommendations:</u>

Public policy needs to guide innovation in new and emerging technologies so as to support sustainable development, while dealing with any negative effects and ensuring that no-one is left behind.

Experience shows that over time new technologies are likely permeate to various sectors of the economy and social activities. In these circumstances, developing countries should deliberately adapt and use automation to increase productivity, promote economic diversification and create jobs.

Governments can facilitate dialogues between workers and employers.

Policymakers need to consider how people can acquire the necessary digital skills and competencies to adopt and adapt frontier technologies into countries' existing production bases. Digital competencies include technical skills, but also generic and complementary skills. Skills are needed at all levels from the basic ability to adopt new applications and products, to the higher-level ones.

Governments should strengthen social protection systems to provide safety nets for workers who may lose their livelihoods. They should also enable these workers to move to new jobs and economic activities by matching their skills to future needs, reforming education, and training systems, and promoting lifelong learning.

Workers who cannot be trained or retrained, and lose their jobs, should be able to rely on stronger mechanisms of social protection and workfare as well as on different forms of income redistribution such as negative income tax, and universal basic income.

Digital policies should be calibrated according to countries' readiness to engage and benefit from the digital economy.

Governments should facilitate women's access to technology, ensuring that they participate in setting priorities, shaping policy decisions and creating research and development agendas.

Country-wide access to electricity and to ICT should aim to bridge gender, generational and digital divides. Through inclusive National Digital Agendas countries can focus on the furthest behind, leveraging ICT infrastructure and improved Internet access through fixed or mobile broadband.

The international community should encourage girls and women to study and seek employment in science, technology, engineering and mathematics (STEM) fields, which have driven the rapid development of frontier technologies.

Women should have full access to all forms of technology and be able to help set priorities, participate in decision making and shape research and development agendas.

Governments and the international community need a much better understanding of the gender impact of technological change.

Governments should explore ways to make goods and services that use frontier technologies benefit vulnerable and low-income groups, including by offering services free, while extending access to digital infrastructure and skills. These efforts can be supported by the international community, which can foster an inclusive global dialogue about all aspects of fast technological change and its impact on society, including the ethical and normative dimensions.

International organizations can help establish appropriate governance frameworks.

ITU/UNESCO's Broadband Commission for Sustainable Development State of Broadband Report 2020

Selected findings:

COVID-19 has demonstrated the unquestionable centrality of connectivity as many adults and children have shifted towards remote work, learning, and communication. At the same time, the pandemic is highlighting inequality among and within countries along a contour line between those with access and those without.

It is important to redouble the commitment to the advocacy targets of the Broadband Commission, promoting universal broadband, if the SDGs are to come within reach.

There is an urgent need for creating enabling policy and regulatory frameworks that can play a facilitating role, including through the government policies needed to prioritize broadband as basic infrastructure.

COVID-19 has demonstrated the need to accelerate digitization of economies in ways that are inclusive of all people, everywhere.

Selected recommendations:

The report includes recommendations in the form of targets that should be achieved.

Make broadband policy universal: By 2025, all countries should have a funded national broadband plan or strategy or include broadband in their universal access and service (UAS) definition.

Make broadband affordable: By 2025, entry-level broadband services should be made affordable in developing countries at less than 2 per cent of monthly Gross National Income (GNI) per capita.

Get people online: By 2025, Broadband-Internet user penetration should reach: (i) 75 per cent worldwide; (ii) 65 per cent in developing countries; and (iii) 35 per cent in Least Developed Countries.

Build digital skills and literacy: By 2025, 60 per cent of youth and adults should have achieved at least a minimum level of proficiency in sustainable digital skills.

Provide digital financial services: By 2025, 40 per cent of the world's population should be using digital financial services.

Get businesses online: By 2025, improve connectedness of Micro-, Small- and Medium-sized Enterprises (MSMEs) by 50 per cent, by sector.

Achieve gender equality in access to broadband by 2025: By 2025, gender equality should be achieved across all targets

ESCWA's report on Big Data for Good: Can Big Data Illustrate the Challenges Facing Syrian Refugees in Lebanon?

Selected findings:

Timely and accurate statistics are a crucial element in the policy-making process for crisis responses, which necessitate accurate and near-immediate information to inform policy makers on the magnitude and extent of the threats and vulnerabilities. With the advent of the "Big Data" era, non-traditional data sources can be leveraged to offer valuable insights for policy makers, especially in crisis response.

Disparate data sources, such as mobile phone call detail records and databases, for example the Database of Events, Language, and Tone, are able to predict the demographic and economic characteristics of communities despite high levels of data aggregation.

Strong partnerships are useful for accessing data and ensuring the appropriateness and soundness of research using such information sources, as well as upholding appropriate ethical standards.

A response to the UN Technology and Innovation Report 2021

Špela Stres, Innovation and Technology Transfer Center, Jozef Stefan Institute, Slovenia

Note: The following is a discussant perspective on the UN Technology and Innovation Report 2021 entitled »Catching technological waves: innovation with equity« by a member of the TFM 10-Member-Group.

First, it is now my turn to thank the authors of this breakthrough report for their honest and transparent view of the current world situation, the reasons that have brought us here and the future that lies ahead if we do not act promptly.

Indeed, until about 1800, the development of humanity was reasonably homogeneous throughout the globe. After that, it is correct to say that the islands of individual development began to diverge. Europe, the USA, Canada, Australia, etc., advanced through technological development faster than other societies. They rose in terms of an economically more comfortable life, with better opportunities for ever-faster progress. More options for learning, for sharing what has been learned, for new, even more significant progress did not give rise to the need to share benefits with the rest of the world. Still, the most advanced countries behaved somewhat in an isolationistic manner. In particular, such conduct is less or even unacceptable if we are aware that the first impetus for faster progress historically came not from the internal reserves of fast-growing economies but from the colonialist success that began as early as the Middle Ages. In addition, such behaviour is unacceptable for all those who have found themselves in the new global middle class in the last century - their shoulders are the ones who bear the weight of growing inequality with the wealthiest islands in the world, which are becoming smaller but richer. Therefore, the consideration of how to proceed is more than in place.

I am not the product of a long aristocratic line that would benefit from Third World wealth as early as the 16th or 17th century, and I also doubt that anyone in my area belongs to this group. I come from Slovenia, a small country in the very north of the Balkans, where we lived sandwiched between the powerful imperial families of the Habsburgs and the sultans of the Ottoman Empire. Before the Second World War, there were only workers and farmers at our end of the world, most uneducated. However, in 1919 we forced permission from foreign dignitaries to establish our first very own university. I am a product of the socialist vision, which in Yugoslavia after the Second World War made it possible for everyone capable of study to do so and so my parents went to that same university. However, socialism also meant that nationalization processes took most of the property away from the people to make it nationally owned. Thus in effect, after 1945, the people became much more impoverished than before. So these people could study even though it meant starvation for them during their studies.

Today, the situation globally speaking is not much different. We mustn't forget that there is more to the world. To stimulate the growth of new industries and services that produce jobs and wealth and promote human development, developing countries and developed ones will need to set strategic directions through national plans for research and innovation. And to do so, they will need in pursuing the policy objectives to overcome several challenges. For example, the report rightly tells us that the developing countries typically innovate by emulating industrialized countries: absorbing and adapting new technologies for local use, but this process is slowest in the poorest countries. It tells us that most developing countries have increased their R&D expenditures, but these are still relatively low. The African Union, for example, has established a target of one per cent of GDP, but on average sub-Saharan African countries are still at 0.38 per cent. And the nominal value of GDP per se is not as high there as in any European country. There is very little private funding of industrial technologies for production applications, so IPR as a precursor for private financing is just a dream. The report also tells us that stringent intellectual property protection that the developed world is promoting will restrict the use of frontier technologies that could be valuable in SDGs related areas such as agriculture, health and energy.

So, on the one hand, we need the IPR to be the cornerstone of the future economy, understanding that any breakthrough tech offsprings will be firmly dependent on IPR to attract private financing. On the other hand, this is still a posh sport (playing polo in a Ralph Laurent T-shirt.

Ah! I am not sure if you care to discuss this, too, just saying that every coin is two-sided. But either way, I take it, there is no benefit in looking away from the topic at hand, so we might just as well address it.

IP is key to ensuring investor confidence, as initially, the investors do not know the people (team) and its culture, nor do they know the technology well. They can only assess the market need. On the other hand, IP is only a partial response to the investor's need to protect their investment - in the early stages of technology development, the valuation is rarely accurate or is subject to significant fluctuations in value due to inaccurate information. There are different methods (market value, investment estimate, expected turnover) to perform the IPR valuation. Still, they are only partially helpful in determining the actual value, so expectation plays a significant role.

Nevertheless, IP plays a crucial role in obtaining funding already for (earliest stage) Proof of concept (POC) funds, which are supposed to invest in the riskiest technologies. POCs also expect researchers to incorporate the company as soon as possible and transfer IP rights to it in full. In this way, PoCs want to establish a well-defined business relationship between the investor and the contractor, and the only thing they have to work with, in the absence of significant equipment and set processes in the company is IPR;

There are, however, examples of successful mechanisms that smoothly support the technological development and should be looked into also for the benefit of the developing countries: The EIC, with its continuous path whereby an inventor can obtain uninterrupted financing if it meets the conditions and its solution has moved to the next level with the funding of the previous phase, provides an excellent example of a policy to develop IP-based financing (from building the IPR portfolio in the Pathfinder to executing together with IP valuing VC funding in particular in the Accelerator phase) for early technological breakthroughs and should be used wider throughout the European national financing institutions;

Also, the Horizon Europe 2nd pillar projects can be interesting for an evaluation of attracting private investments. IPR can also be a critical decision-making factor for working with industrial partners (who also represent private investment). However, industry perception of IPR within the EU varies between countries. While in some countries it is self-evident to discuss licensing agreements and the transfer of IP rights when concluding collaborative agreements, a patent is still seen as an unnecessary cost rather than an added value for the cooperation in others;

We should improve IP based financing and support IP financing markets to develop further, to build further awareness and trust between the investor market and the inventor companies. It should be done so that the governments will finance R&D while requiring that the benefits of this research serve the public good. And here we are at the crucial concept of enabling the »doing good« process, hidden in the Open science concept. The Unesco recommendations will be presented publicly in May 2021 and adopted in November 2021. This will probably, together with the IPR protection, be one of the cornerstones of future development.

We can now conclude. If we are but children playing in the ocean waves in the sand, we can be reconciled – we can catch the technological waves.

V. Conclusion

The latest science-policy briefs and updates on country experiences, specific solutions and activities build on and complement earlier submissions of such contributions on emerging technologies to the analytical working group in the IATT. For example, the comprehensive collection of "Science-Policy briefs on the impact of rapid technological change on the Sustainable Development Goals"[216] of 2019 contains a large number of contributions on artificial intelligence; the new production revolution, inequality, and ethical aspects; nanotechnology; biotechnology; green nexus technologies and others. They all remain valid, and together with the new submission in the present report, they provide a mosaic of key issues and proposals that have been put forward for potential consideration in the UN agenda. Contributing volunteers have dedicated many hours of work to highlight issues they feel passionate about. It is up to all of us to examine proposals, discuss solutions, learning from each other, and considering follow-up action on the most useful and relevant suggestions.

In the beginning of the report we asked, how are things different in the face of our experience with COVID-19? What does it mean for the way forward? The TFM finding which we presented in Chapter II provided a partial answer. In particular, the 2019 TFM findings remain valid, but new elements are necessary.

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 findings and recommendations in this report stand to be refined further through discussions in the TFM 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.

[216] https://sdgs.un.org/sites/default/files/documents/22739Rapid_tech_change_policy_briefs_for_Web_v2.pdf