WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

As part of Frontier 2030: Fourth Industrial Revolution for Global Goals Platform

Unlocking Technology for the Global Goals

In collaboration with PwC

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About Frontier 2030: Fourth Industrial Revolution for Global Goals Platform

The potential of Fourth Industrial Revolution technologies to tackle major global challenges – such as poverty, climate change, nature loss and inequality – is immense, yet this potential is far from being reached. To this end, the Forum's Centre for Global Public Goods is scaling up efforts to proactively engage stakeholders to channel Fourth Industrial Revolution innovations towards positive social, economic and environmental outcomes through a series of initiatives.

Frontier 2030 – a new Fourth Industrial Revolution for Global Goals Platform, which this report supports, aims at facilitating the application of advanced technologies to help achieve the Sustainable Development Goals (herein referred to as the Global Goals). It builds on calls from the United Nations (UN) High-Level Panel on Digital Cooperation for a multistakeholder approach that brings together technology companies, government, civil society and international organization leaders to collaborate and unlock broader barriers to responsible deployment of new technologies to deliver positive societal impact.

Frontier 2030, launched at the World Economic Forum Annual Meeting in January 2020, will provide a focal point for the mobilization of a more concerted and cooperative effort to apply advanced technologies to the achievement of the Global Goals. It will serve, on one hand, as a global node and facilitator of networks of providers and users of technology solutions for sustainable development; on the other, it will advance intentional curated efforts, partnership building, government capacity development and finance to fast track new technology solutions for the Global Goals. The effort will be organized and delivered in cooperation with partner institutions, including leading international organizations.

As a complementary initiative, UpLink is also being launched – a new digital platform to crowdsource ideas and solutions from younger generations and entrepreneurs to progress the Global Goals. Together with the Forum's Centre for the Fourth Industrial Revolution Network – a hub that works with governments around the world to shape policy frameworks – these initiatives form vital building blocks of the Forum's efforts to accelerate the benefits of the Fourth Industrial Revolution for inclusive, sustainable and human-centred development.

PricewaterhouseCoopers (PwC) has been at the heart of the Forum's Fourth Industrial Revolution for Public Goods journey; it is a key knowledge partner for Frontier 2030 and has led this new report to coincide with the platform launch. The World Economic Forum, PwC and other partners will work with a community of influence to mobilize new technologies for the benefit of the Global Goals.

Foreword

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Fourth Industrial Revolution innovations, including AI, blockchain and the internet of things (IoT), are having an increasing impact on economies and societies. Distinctions between the physical, digital and biological realms are becoming increasingly blurred, and cyber physical systems are emerging. It is rapidly transforming business models and industries globally, with huge advances at the cutting edge of many sectors, including healthcare, agriculture, energy, education and transport. The speed and scale of advances in the past few years alone has been immense: The global big data market almost doubled in market size in three years with a total revenue of $49 billion in 2019;[1] worldwide spending on artificial intelligence (AI) was approximately $35.8 billion in 2019, with a 44% increase from 2018,[2] and for blockchain solutions nearly $2.9 billion was spent in 2019, an increase of 88.7% from 2018.[3] The first fully electric aeroplane made a successful virgin voyage in November 2019[4] and 5G is no longer a potential future but the reality in more than 13 countries.[5] Meanwhile, the risks associated with technologies went from theoretical to real as a research centre used CRISPR gene editing for the birth of two babies,[6] democratic elections were influenced through the misuse of technologies[7,8] and, as self-driving cars were increasingly introduced in cities around the world, so were the first casualties.[9]

As such technological advances bring us daily benefits, they also raise a host of complex questions and broad concerns about how technology will affect society and our planet. Previous industrial revolutions have radically improved the standards of living for human beings, but not only are these gains unevenly distributed across geographies and demographics, they have come with the degradation of our planet's health.[10] Today's technological revolution must break this pattern and, for the first time, deliver sustainable, inclusive economic growth. In 2015, United Nations member states agreed on the Global Goals for a better world by 2030; 17 Goals that provide a framing for society's grand challenges. Progress towards delivering upon many of these goals is far off track, from eliminating extreme poverty[11] to combating climate change and rapid nature loss. These Goals could not provide a clearer framing for where we need to assertively point the power of new technologies to deliver for humanity.

Ensuring that we harness the Fourth Industrial Revolution responsibly to accelerate progress to the Global Goals is a huge opportunity for the 2020s. As this report shows, although the landscape of opportunity is significant and new technologies could support progress across the Goals, substantial barriers and risks exist. Multiple challenges can prevent scaling of new solutions, whether from lack of basic infrastructure, expertise, data and adequate market incentives, or through to trust, performance and security concerns. Moreover, if these technologies are not scaled in a smart and sustainable way, they could exacerbate problems for people and the planet, putting further strains on our society and environment. Well-known examples include how to use data while ensuring people's right to privacy, protecting against the misuse of AI for crime or warfare, or to influence democracy, job displacement from automation and the energy consumption challenges of new technologies such as blockchain.

For the Fourth Industrial Revolution to be successful, it will need to work for the economy, society and environment, and for the benefit of everyone. Fortunately, many of the innovations and applications we have identified could be used across a much broader range of Global Goals, geographies and demographics. It is time to get the enabling environment right to deliver on this enormous promise, including through leadership and new forms of multi stakeholder collaboration, targeted R&D, more active and intelligent policies and regulation, rapid upskilling and reskilling, and the right incentives to stimulate market solutions.

This report is an initial step in building the case for how advanced technologies could do more to accelerate progress towards the Global Goals. Covering 17 Goals and more than 10 vital Fourth Industrial Revolution technologies presents a monumental task to convey the landscape, barriers and potential in a single report. Not just because of the breadth and depth of the Goals but also because of their interconnectedness as economic, social and environmental systems; combined with widely different starting points, for example on digital readiness, across countries and global regions. There are, of course, many different aspects to examine and areas to explore, but we know there is very limited time. Here, we hope these insights, examples and our recommended call to action will spark a sense of urgency and increased interest, investment and efforts to ensure that these technologies are fully harnessed to enable our Global Goals to become a reality by 2030.

Executive summary

Through an analysis of over 300 Fourth Industrial Revolution technology applications, this report maps the breadth of the opportunity for new technologies to make a significant contribution to the achievement of the Global Goals. Through this analysis, this report will explore: 1) the extent to which this opportunity is being realized; 2) the barriers and risks to scaling these applications; and 3) the enabling framework for unlocking this opportunity.

Our analysis showed that based on current applications, Fourth Industrial Revolution technologies could have a high impact in particular across 10 of the goals, and that 70% of the 169 targets underpinning the goals could be enabled by existing Fourth Industrial Revolution technology applications. Analysis of the applications database highlights that there are a number of common transformative characteristics enabled by these innovations. These include: increasing the productivity of systems; enabling transparency and stakeholder accountability; aiding the shift to decentralized systems; supporting new models to unlock finance; and accelerating discovery from new insights to new materials.

While there is an enormous opportunity, some important barriers will need to be overcome. These include poor data access and quality, a lack of basic infrastructure, an inadequate governance and policy environment, upskilling and reskilling needs and – in particular for public goods-focused solutions – a lack of viable business models and commercial incentives for scaling. In addition, the scaling of new technology applications creates new risks – from security and control risks to socioeconomic risks including job displacement or even unintended environmental risks – that also need to be actively and assertively managed by the tech sector, industry and governments alike.

A set of enablers is needed to continually accelerate innovation and investment into new solutions that help tackle our grandest challenges, and to create viable markets for those solutions in the long term. These include:

1. Responsible technology governance: development, alignment and uptake of responsible technology principles by tech firms and broader stakeholders.

2. Leadership to mobilize commitment and standards: agendas to set ambitions and enable action and investment in the use of technology aligned to progressing the Global Goals.

3. Partnerships for collaboration and collective action: cross-sector and within-sector collaboration and coalitions to drive impact and systemic change at scale.

4. Public policy and regulation for the Fourth Industrial Revolution: priority-targeted policy and regulatory approaches to safeguard risks from the Fourth Industrial Revolution and scale solutions for positive societal impacts.

5. Finance mechanisms to stimulate market solutions: targeted public finance and blended finance approaches to scale Fourth Industrial Revolution solutions where there have been market failures or where the benefits are largely for public goods.

6. Breakthrough innovation: collaborative R&D agendas to outline priority problems to direct public and private innovation finance, talent and collaboration.

7. Data and tools: new models for democratization of data, APIs and tools to spur scaling of Fourth Industrial Revolution applications for the benefit of everyone

8. Capacity development and skills: active and collaborative agenda on upskilling and reskilling, and interdisciplinary talent to maximize value from the Fourth Industrial Revolution.

In line with these enablers, we have outlined what a leadership-level "call to action" could look like for technology executives and government leaders in order to deliver ambition and investment around technology opportunities for the Global Goals. This includes commitments to implementing strong, responsible technology frameworks to drive fit-for-purpose policy and regulation, upskilling and reskilling, financing, data commons efforts, directed R&D and even driving labour-market reforms.

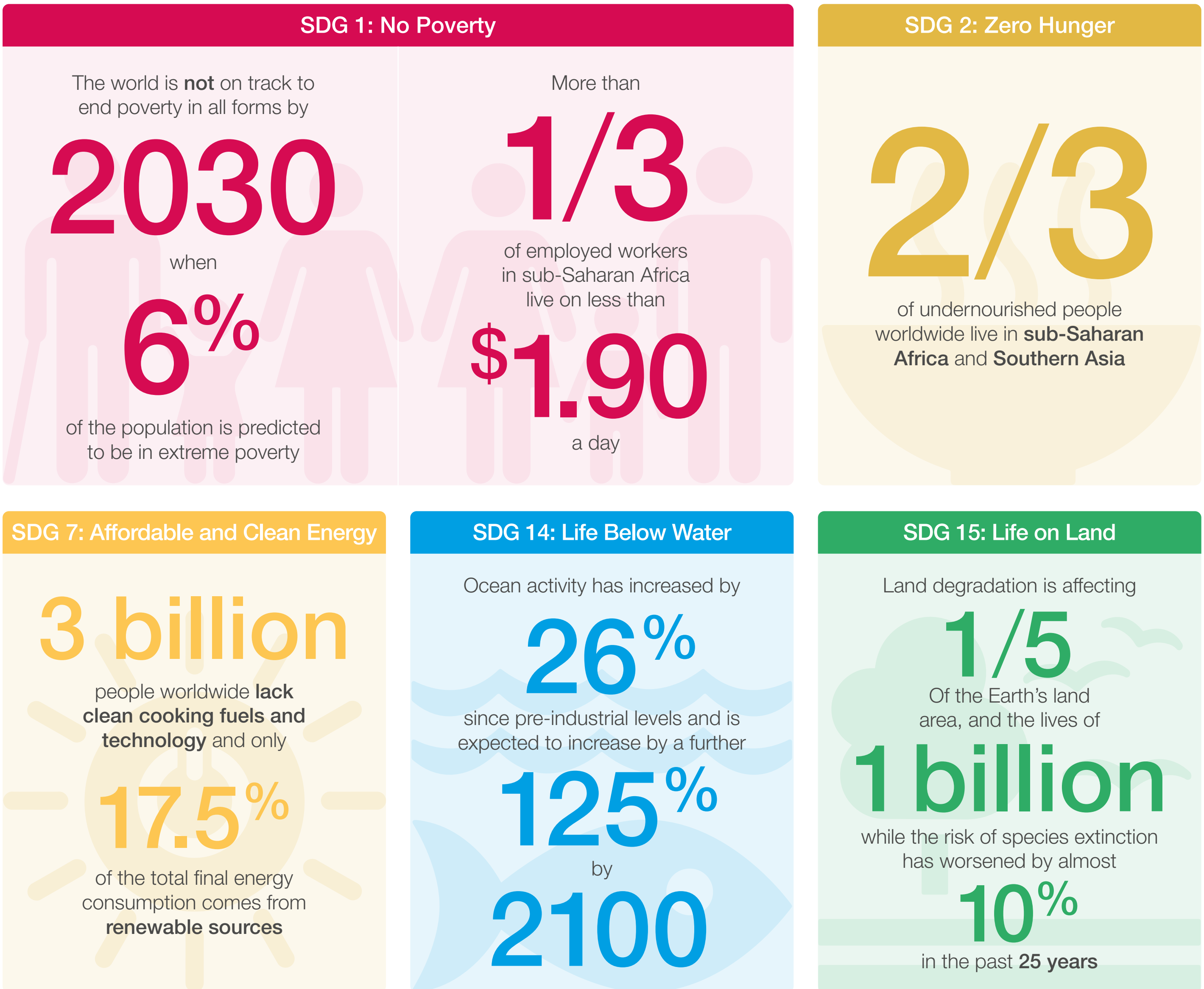
It is crucial to find new ways of leading, working and innovating to unlock and scale the promise of the Fourth Industrial Revolution for people and the planet. For many of the challenges faced, from climate change to nature loss, there is no longer the luxury of time. It is vital to move quickly beyond celebrating a promising set of "for good" use cases, to leadership ambition in investing money, time and expertise, and fully embracing this agenda. Harnessing technology is no silver bullet, but these developments could be an essential building block in the ability to achieve the Global Goals this decade.

Chapter 1: A decade to act: the challenge and the opportunity

Accelerating action to achieve the Global Goals

Progress to reach the UN Global Goals for sustainable development by 2030 is not on track (for definitions of the 17 Goals, see Annex 1). Despite progress in a number of areas on some of the Goals since 2015, the global response has not been ambitious enough: on some of the Goals, progress has been slow or even reversed.[12] The recent Sustainable Development Progress Report showed that: the world is not on track to end poverty by 2030; 785 million people still remain without basic drinking water; and we are not on track in terms of economic and inclusive growth targets for developing countries and industrialization in these countries is too slow to meet the 2030 agenda target, not least in technology-related sectors. Meanwhile, the report showed that the global material footprint is growing, outpacing population and economic growth, and that we are far from being on track in our efforts to combat climate change and protect biodiversity. Performance across targets and within targets is also uneven. In OECD countries, Goal 5 on gender equality sees countries being close to the target of women using the internet, but the same countries are far behind when it comes to the gender gap in unpaid work.

Figure 1: Key facts from the Sustainable Development Goals Report 2019



Many of the efforts to date have concentrated on areas in which progress is more readily achieved. For example, massive and persistent investments in primary health and education globally over the past decades has resulted in change in life expectancy at birth and access to primary education. The real challenge lies where progress is not so easily achievable, including complex systemic global issues such as climate change, biodiversity loss and ocean health, all areas in which planetary boundaries have been crossed[13] and where we are running out of time to address major problems. Likewise, progress is lagging in parts of the world where it is hardest to drive structural socioeconomic change. The recent Human Development Report from the United Nations Development Programme (UNDP) showed countries with a low human development index (HDI) are catching up in basic capabilities, with a 5.3% change in primary education between 2007 and 2017 and a 49.3% change in mobile-cellular subscriptions in the same time period. However, these same countries are falling behind in some of the most defining areas for an inclusive Fourth Industrial Revolution. Between 2007 and 2017, the change in tertiary education was only 1.1% for countries with a low HDI while it was 7.1% for countries with a high HDI. Similarly, less than 1% of countries with a low HDI have broadband access compared to 28.3% of countries with high HDIs.[14]

Business as usual is not an option: Choosing to “wait and see” will put impossible environmental and social strains on people and our planet. The years 2020 to 2030 mark the so-called “decade of action”, in which ambitions must intensify and plans must turn into reality. Performance to date on the Global Goals suggests that traditional policy and market responses will not get us there fast enough, particularly at a time when society is increasingly fractured. For instance, on Climate Action (Goal 13), it has been four years since the global Paris Agreement, but national pledges still take us to a dangerous world of 3ºC global warming by the end of this century[15] . Business action is accelerating yet there is still a long way to go. Getting to the “net zero emissions” economy that governments around the world have signed up to, and that scientists say must happen by 2050,[16] requires radical transformation of every sector of the economy. Heavy industry, our energy grids, transport, food and agriculture, buildings and cities, and production and consumption will need to undergo rapid decarbonization.

Transformative change and innovation across all sectors of our economy is needed to unlock the environmental, economic and social transformation required to tackle climate change, and achieve the Global Goals by 2030. We need to embrace innovation not only to change how we do things but also to broaden the set of tools we use to solve problems, including new models of collaboration, new business models (platforms and ecosystems, marketplaces, digital commons) and the powerful new technologies of the digital age.

Steering the Fourth Industrial Revolution to realize the Global Goals

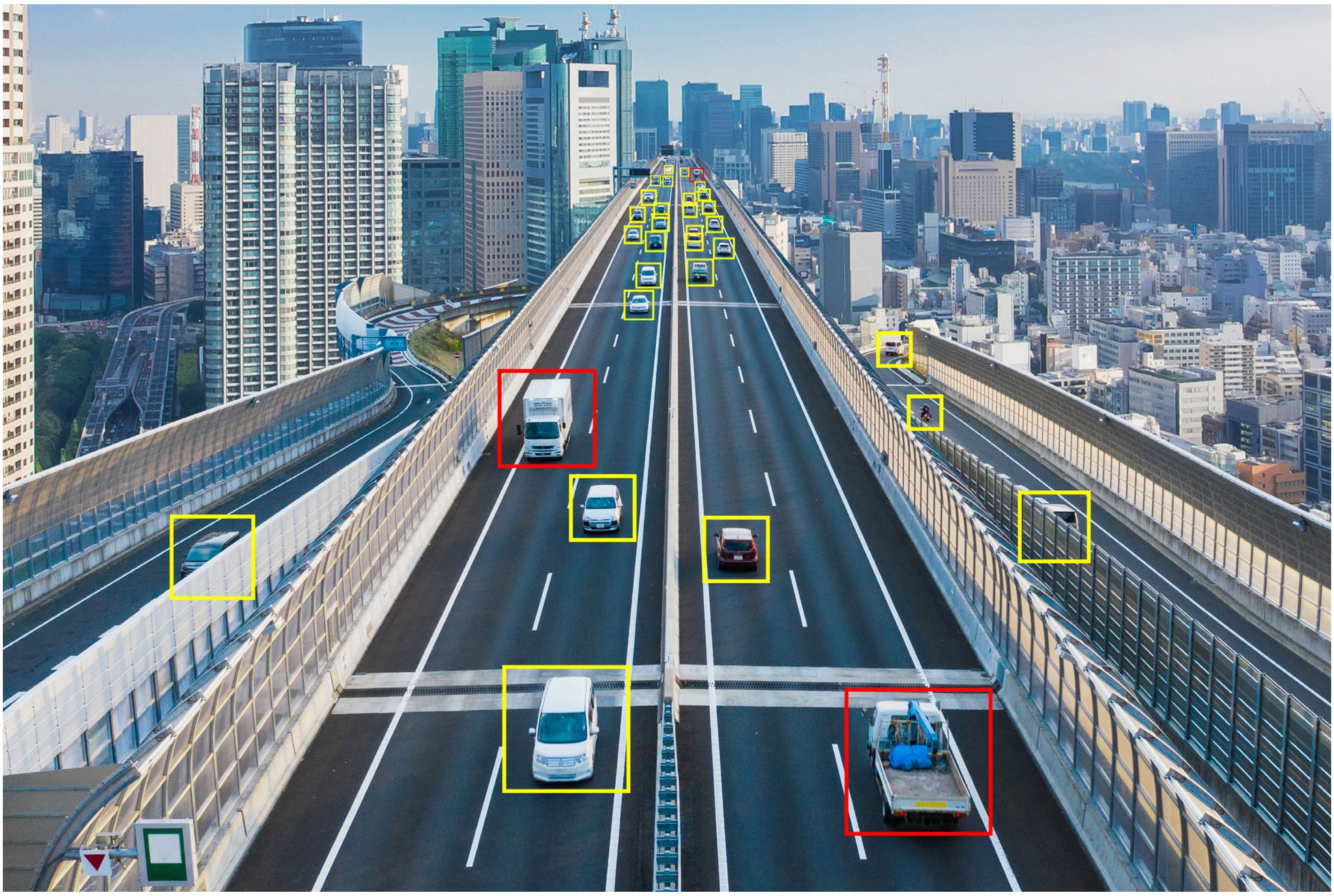
Against the backdrop of these global challenges, the Fourth Industrial Revolution is reshaping industries and value chains, scientific discovery, human engagement and even national economic power at unprecedented speed and scale. AI, robotics, blockchain, IoT and 5G connectivity, advanced materials and biotechnology are already reshaping society (for Fourth Industrial Revolution technologies, see Annex 2). Today Facebook users collectively have a larger population than China or India,[17] and Apple is worth more than the entire US energy sector.[18] In the less than three years since the first drone pilots delivered blood in Rwanda in late 2016, drone operations are now being scaled and even standardized in mining, agriculture and healthcare in more than 23 countries in sub-Saharan Africa.[19] In 2019, two-thirds of customers globally interacted with a chatbot rather than a human.[20] More broadly across the economy, an estimated 70% of new value created over the next decade is being based on digitally enabled platforms. Taking AI alone, estimates by PwC suggest that AI could increase global GDP by $15.7 trillion by 2030.[21] Companies are reimagining how we innovate, create, distribute and capture value in this new environment, and in many cases to build or be part of ecosystems that will transcend industry boundaries.

On the flipside, market disruptions and a rapidly evolving competitive landscape are raising existential questions on the future strategy and operating model for companies. The life expectancy of a Fortune 500 firm has fallen from 75 years in the early 20th century to only 15 today. Companies are responding – in 2018 an estimated $1.2 trillion was spent by companies on digital transformation efforts[22] – but most efforts fail to deliver sustainable digital transformation[23] and most companies do not feel equipped to embrace technological shifts. Just looking at AI, 85% of chief executive officers surveyed globally say AI will significantly affect the way they do business in the next five years. This leaves business and industry with a dual challenge: staying ahead in a rapidly disrupted world while repurposing their business model – whether technology-driven or technology-creating – towards faster and better realization of the Global Goals.

Despite a rapid rise in Fourth Industrial Revolution technologies being applied across many aspects of industry and commerce, the potential of new technologies to accelerate progress to the Global Goals is only just beginning to be realized. Our analysis suggests that adoption of these technologies is patchy and tends to be focused on areas that maximize private-sector commercial benefits, including energy, industry and healthcare, rather than those areas of the Goals that might largely benefit wider society.

A lack of social acceptance can also affect adoption rates of technology solutions. Trust and acceptance both of new technologies and tech service providers is a prerequisite for their success, and a major barrier to entry for many technology offerings. This is particularly apparent for sectors in which industry is largely not yet digitally native. This barrier raises a specific challenge for engaging entrepreneurs, and investors for the Global Goals. As an example, more than a third (35%) of business leaders believe drones are not being adopted in their industry because of negative public perceptions.[24]

There is a huge untapped opportunity to harness new technologies to accelerate progress on the Global Goals, both broadening and deepening current action. Through this study, we have found that Fourth Industrial Revolution technologies could have a “high” impact across more than half of the Goals, and just over two-thirds of the 169 targets underpinning the Goals could be bolstered by technological innovation. Perhaps more strikingly, big data platforms and AI have the potential to support progress towards each and every one of the Global Goals (the full analysis is presented in Chapter 2).



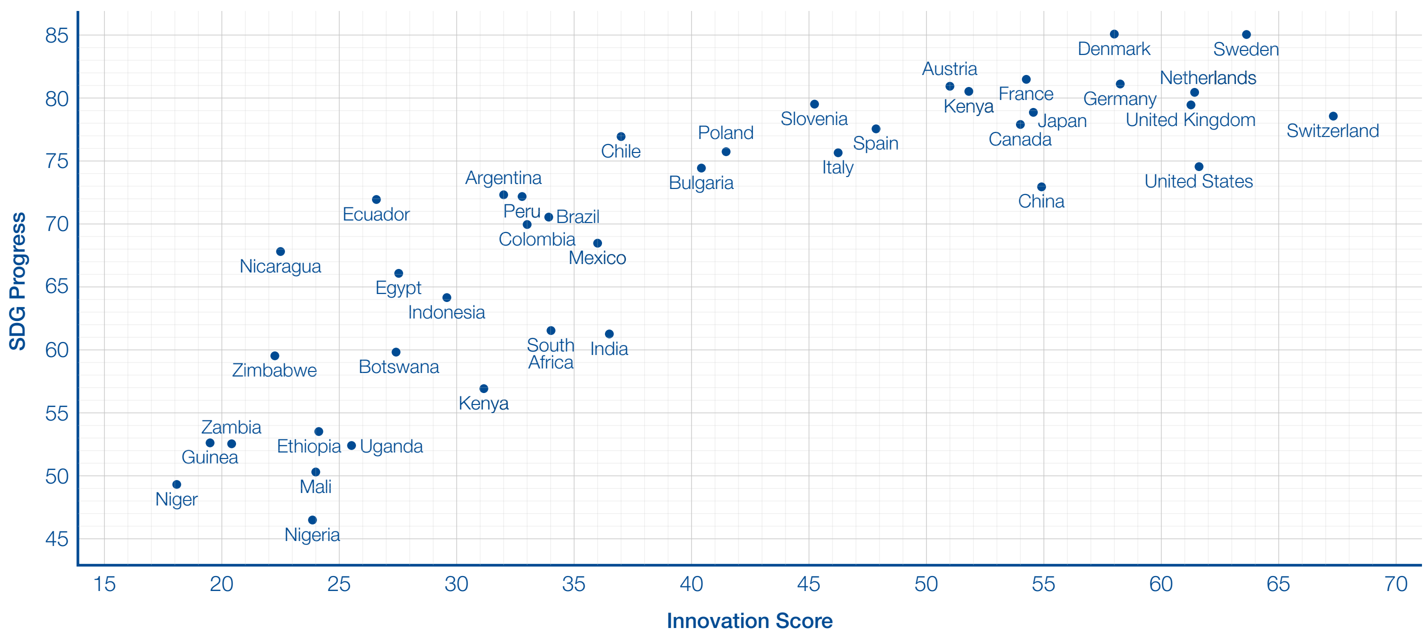
At a country level, we see a strong relationship between countries' ability to innovate and their progress on the Global Goals. Technology adoption and economic development is inherently linked. Countries that have a strong digital readiness and innovation capacity have often made most progress on the Global Goals whereas countries with less innovation have generally fared less well (see Figure 2). Research from PwC and Microsoft shows that the economic and environmental gains of applying AI to tackle environmental challenges would predominantly be captured by Europe, East Asia and North America due in large part to each region's current digital readiness and levels of tech adoption.[25] There is an opportunity to build and strengthen innovation capacity nationally and regionally to accelerate Global Goal progress, bolster sustainable development and unlock huge potential. There is also a market opportunity, which has been estimated at more than $12 trillion annually by 2030 from achieving the Global Goals in the areas of food and agriculture, cities, energy and materials, and health and well-being systems alone.[26] Society stands to benefit hugely in parallel, too.

It is fair to ask why there has been such limited progress to date.[29] The reason why Fourth Industrial Revolution tech is not fully deployed in support of the Global Goals is a result of various barriers, most notably governance and policy, funding and resources for R&D and deployment, insufficient collaboration, as well as the maturity of data, technology and infrastructure. For all of the potential that scaling Fourth Industrial Revolution technologies offers, technology also poses risks that can affect individuals, organizations, the environment and society. These risks tend to fall into two categories, those in design and development, and those in deployment. We explore barriers to scaling technology and risks of deployment in Chapter 3.

Given the risks, and barriers to scale, harnessing Fourth Industrial Revolution technologies successfully to meet the Global Goals will require multiple stakeholders working collaboratively. These actors include governments and regulators, the tech sector, industry, investors, academia and civil society organizations. Some actors and organizations are starting to do this, but many more are not. The flow of finance, technology transfer, capacity building and trade, particularly between the Global North and the Global South, all need to be rapidly strengthened in the 2020s.[30]

In Chapter 4 we lay out how to develop a comprehensive enabling environment to support a more long-sighted and principled approach that actively manages the role technology can play for society and the environment through a set of proactive steps (or so-called "enablers"). Chapter 5 sets out conclusions, including how to align a public-private response through a clear and succinct "blueprint for action" for leaders. Finally, chapter 6 outlines our conclusions including the importance of a public-private platform for sustained action and collaboration.

Figure 2: Capacity and success in Innovation vs. Global Goal progress, by country



Innovation Score vs. SDG Progress. The marks are labelled by Country. The data is filtered on country as an attribute, which keeps no members. The view is filtered on Innovagtion Score, which keeps non-Null vallues only.

Source: 2019 Sustainable Development Report (https://s3.amazonaws.com/sustainabledevelopment.report/2019/2019_sustainable_development_report.pdf),[27] the Global Innovation Index 2019 (https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2019.pdf)[28] and PwC analysis.

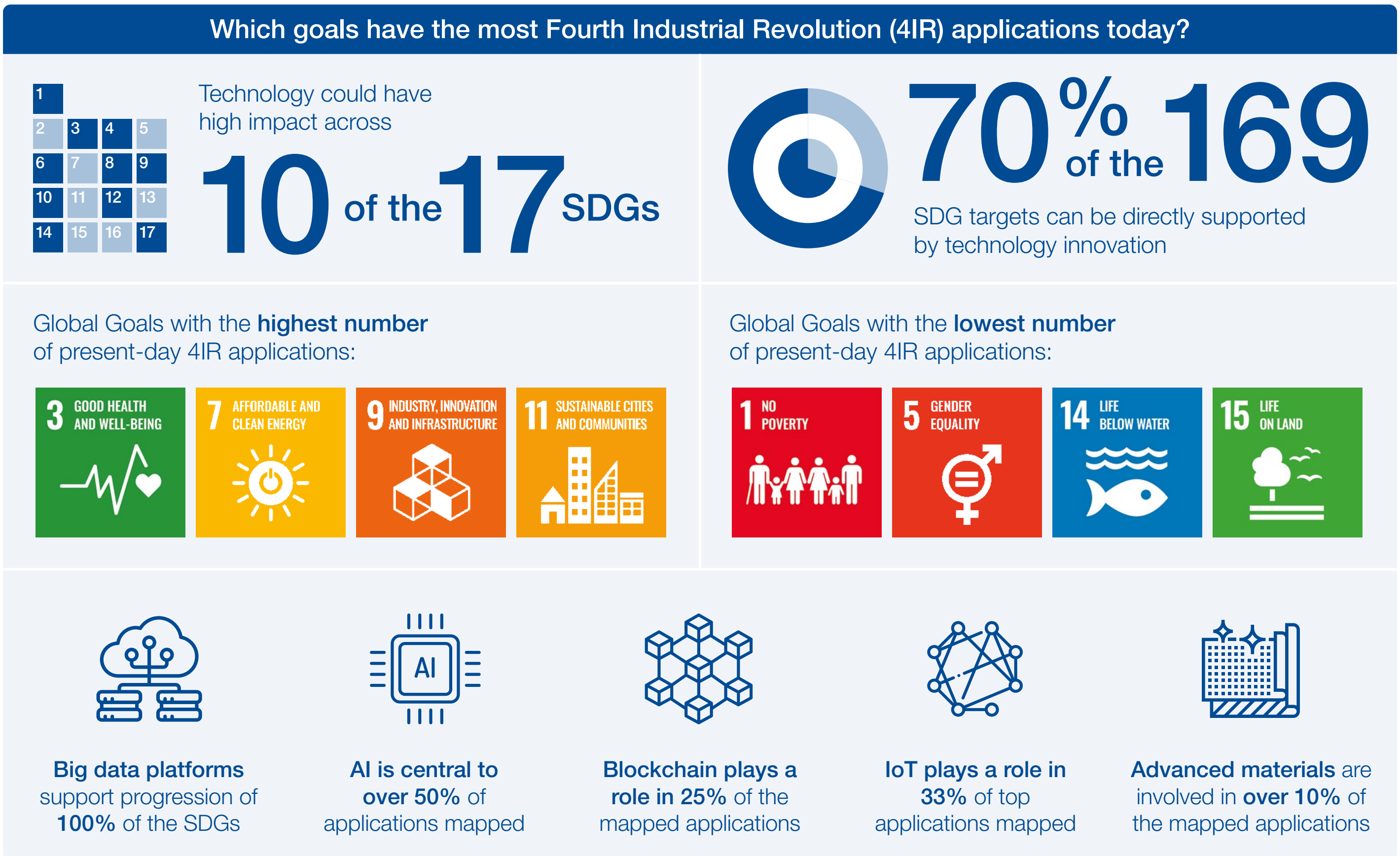
Chapter 2: State of play: technology and the Global Goals

Mapping Fourth Industrial Revolution technology applications across the Global Goals

New technologies have the potential to contribute significantly towards achieving the Global Goals. Through research, analysis and interviews with a range of stakeholders at the forefront of applying Fourth Industrial Revolution technologies in industry, technology firms and research, we have mapped over 300 applications to the Goals (omitting Goal 17 on Partnerships). For each application, we have captured metadata on geography, technologies harnessed, specific goal affected, priority challenge areas addressed for each goal (e.g. for Climate Action, this includes clean transport and sustainable land use), maturity of deployment, important partnerships and enablers, and barriers to scale.

Our research found that across the Global Goals and their 169 targets, 70% of the targets could be enabled by Fourth Industrial Revolution technology applications already in deployment. The applications were found to be playing an important role in 10 of the Global Goals in particular, with Health (Goal 3), Clean Energy (Goal 7) and Industry, Innovation and Infrastructure (Goal 9) as those with the highest number of Fourth Industrial Revolution applications already in use. This result is not surprising from a financial standpoint, given that these goals are strongly tied to private-sector markets. For example, the healthcare market is one of the biggest industries in most countries, bringing in more than $2.8 trillion annually in the United States alone.[31] Health and energy are also sectors in which investment in digital innovation is rife, from big tech companies expanding into these industries – public- and private-sector investment in healthcare AI is expected to reach $6.6 billion by 2021.[32] In contrast, the lowest number of present-day Fourth Industrial Revolution applications were found to occur across No Poverty (Goal 1), Gender (Goal 5) and Life Below Water (Goal 14). These Goals are, in the broadest sense, either recognized as being linked with market failures (1 and 5) or considered a public good (14).

Figure 3: Summary of Fourth Industrial Revolution for Global Goal applications database



Source: PwC Research

Prominent Fourth Industrial Revolution technology applications for the Global Goals

In Table 1, we identify some of the most prominent Fourth Industrial Revolution applications from our research that are being implemented in practice today for each of the Goals. These are not meant to be exhaustive, but to be representative of the most prominent innovations selected on the basis of satisfying five main features:

- **Feasibility proven** (i.e. the application is being deployed and creating impact today)
- **Transformational impact** (i.e. the solution directly addresses the priority challenge areas underlying the goal(s) and could disrupt current approaches)
- **Adoption potential** (i.e. the potential population size is large)
- **Technology centrality** (i.e. Fourth Industrial Revolution technology is a vital cog in the solution)
- **Realizable enabling environment** (i.e. policy and governance requirements can be identified and supported)

While all of the applications in Table 1 are “in vivo” in society today, they are at varying levels of maturity, which for simplicity of illustration have been classified into low (emerging), medium (improving) and high (mature). In practice, emerging solutions (low maturity) may be more nascent, but over the coming decade leading to 2030 they could still outperform mature solutions (high maturity) in terms of impact, if the enabling environment is supportive and/or the solution itself has a large market and high disruptive capability (e.g. low-cost low-greenhouse gas (GHG) synthetic proteins for achieving Climate Action impact).

Table 1 (pt1 of 6): Prominent Fourth Industrial Revolution-enabled applications for Global Goals 1–16, and their maturity

1 NO POVERTY

High maturity

- *AI-enabled digital footprint for credit/mobile money access*
- *AI, satellite and drone-enabled disaster risk insurance products (incl. parametric bonds) and microfinance*
- *Advanced demographic data analytics*
- *Blockchain-enabled crowd-finance for development projects and charitable organizations*
- *Inclusion-orientated and community-focused crypto solutions*
- *Smart pay-as-you-go utilities and shared services*

Medium maturity

- *AI-enabled financial market early-warning system*
- *Transparent and trustworthy land-registry platforms and smallholder identity systems harnessing blockchain*
- *Transparent and immutable records of workers' rights and compensation harnessing blockchain*
- *Community-distributed marketplaces for goods and services, incl. peer-to-peer (P2P) trading and smart contracts*
- *AI- and blockchain-enabled skills matching, access and contracting across global markets*
- *Blockchain digital identity solutions to enable economic identities, incl. for refugees*

2 ZERO HUNGER

High maturity

- *AI, satellite and drone-enabled disaster risk insurance products (incl.parametric bonds) and microfinance*
- *Precision agriculture to optimize inputs and returns and early detection of diseases and issues*
- *Agricultural robotics for harvest and process automation and input-output optimization*
- *AI- and sensor-enabled prediction to optimize agricultural and food supply and demand prediction*
- *Low-emission minimum-waste indoor/urbanized farming solutions, including hydroponics and vertical farming*
- *AI-enabled hyperlocal weather forecasting for agricultural management and prediction*
- *Low-cost, low-GHG emissions synthetic proteins*

Medium maturity

- *Blockchain-based food supply chain traceability and management system*
- *Crop biotech solutions to improve resilience, productivity and nutritional content*
- *Community-distributed marketplaces for food and agriculture, incl. peer-to-peer (P2P) trading and smart contracts*
- *AI-enabled extension services for smallholders to increase productivity*
- *Low-GHG emissions synthetic fertilizers, incl. green ammonia and derivative green fertilizers*
- *AI, sensors and blockchain to eliminate spoilage/loss in food value chain, including smart food storage*
- *Precision nutrition optimized for individuals and livestock*

Low maturity

- *Highly customized, 3D-printed food*

3 GOOD HEALTH AND WELL-BEING

High maturity

- *Smart homecare, smart wearables and virtual healthcare assistants*
- *Monitoring and predicting health metrics and disease, including smart implants, wearables*
- *Smart hospital management to improve communication, collaboration and performance*
- *Drones for remote delivery of medicines, medical equipment and samples*

Medium maturity

- *AI-prediction of spread of epidemics/pandemics*
- *AI-enabled analysis of microbial resistance to antibiotics to aid patient care and new antibiotic development*
- *AI- and sensor-enabled remote monitoring and diagnostics for hard-to-reach communities*
- *Advanced healthcare learning, e.g. VR/simulations for virtual patient encounters, AI to form training based on patient results*
- *Blockchain-powered digital identity for citizens enabling healthcare access*
- *Secure blockchain-based patient data storage to streamline records*
- *Smart medical robotics and nanobots to improve surgical performance and access*
- *AI and digital twins to optimize large-scale, high-speed drug trial simulation*
- *Emotion recognition for diagnosis and treatment, e.g. diagnose neurodevelopmental disorders and mental health issues*

Low maturity

- *3D printing of medicines and body parts, and lab-grown synthetic organs*
- *Low-cost personalized medicine (synthetic biology, AI)*

Source: PwC Research

Table 1 (cont. p2 of 6): Prominent Fourth Industrial Revolution-enabled applications for Global Goals 1–16, and their maturity

4 QUALITY EDUCATION

High maturity

- *Smart open educational resources to increase affordability and accessibility*
- *AR/VR training, information and remote learning experiences*
- *Automating and speeding up teachers' tasks*
- *4IR-enabled personalized and adaptive learning, including AI personalized mass online open courses*
- *AI-driven assessments to enable the delivery of continuous feedback*
- *AI-designed digital curriculums, teaching plans and content across devices*
- *Smart tools for school and teacher resource management*
- *Natural language processing (NLP)-enabled voice assistants and speech to text for inclusive learning support*
- *AI-based plagiarism detection, e.g. document scans, tests for plagiarism*

Medium maturity

- *Algorithms to make informed decisions on student learning and deficit*

Low maturity

- *Interactive and multisensory assistive learning to increase student engagement and interaction*

5 GENDER EQUALITY

High maturity

- *AI-enabled digital footprint for mobile money access targeted at women consumers and entrepreneurs*
- *4IR digital applications supporting women and girls, e.g. SafePal app, users can report instances of sexual violence confidentially*
- *4IR-enabled educational platforms targeted at girls and women*
- *AI-enabled remote work platforms to mobilize contingent workforce*

Medium maturity

- *Community-distributed marketplaces for goods and services, incl. peer-to-peer (P2P) trading and smart contracts to facilitate inclusion*
- *AI to identify unbiased selection to support inclusivity*
- *AI-enabled real-time gender data analytics*
- *Inclusion-orientated and community-focused cryptocurrency solutions (e.g. Brixton pound)*
- *Drones for remote delivery of goods, which frees up especially women's time in rural communities*
- *AI-enabled cyber abuse detection of sexual and gender harassment*
- *Open-access gender-equality dashboard at country-wide level*
- *Blockchain-powered digital identity to enable access to services and finance*

6 CLEAN WATER AND SANITATION

High maturity

- *Precision and autonomous irrigation and nutrient prescription systems enabled by AI, robotics, sensors, drones and satellite technologies*
- *Farming technology that minimises water, land and nutrient use, e.g. vertical farming, automated irrigation, aeroponics*
- *Smart water-infrastructure predictive maintenance*
- *AI-enhanced scenario modelling for water infrastructure risks and performance*

Medium maturity

- *4IR-enabled traceability to provide consumer transparency on water source*
- *AI- and IoT-enabled real-time water system insights for water suppliers and users incl. water quality and water availability, and prediction tools*
- *Blockchain platform to cost-effectively crowd-finance clean water infrastructure development*
- *Decentralized water systems with smart contract-enabled peer-to-peer water rights trading and dynamic pricing*

Low maturity

- *Advanced materials for desalination technology*
- *Smart nanotechnology and biosynthetic solutions for water desalination, purification and reclamation*

Source: PwC Research

Table 1 (cont. p3 of 6): Prominent Fourth Industrial Revolution-enabled applications for Global Goals 1–16, and their maturity

7 AFFORDABLE AND CLEAN ENERGY

High maturity

- *4IR-enabled decentralized and coordinated energy-grid management, incl. IoT, AI*
- *Smart infrastructure for operational efficiency and maintenance*
- *Optimized energy system demand and supply modelling and forecasting harnessing AI and big data*
- *Alternative energy asset financing mechanisms (e.g. blockchain finance platforms and mobile money)*
- *AI-enabled virtual power plants to integrate distributed renewable energy sources*
- *AI- and IoT-enabled predictive maintenance of energy infrastructure*

Medium maturity

- *Advanced energy storage (ultra-low cost and high performance)*
- *Printable renewable assets (e.g. solar coatings)*
- *4IR-enabled peer-to-peer renewable energy trading*
- *Blockchain platform to crowd-finance clean energy infrastructure development*

Low maturity

- *Advanced materials for bio-energy carbon capture and storage (BECCS)*
- *Advanced materials and analytics for next-gen thermal storage (ultra-low cost and high performance)*
- *Alternative biofuel production: e.g. algae-derived biofuels*
- *Advanced waste heat capture and conversion*

8 DECENT WORK AND ECONOMIC GROWTH

High maturity

- *AR/VR training, information and remote-learning experiences*
- *Robotics for process automation for increased productivity*
- *AI and big data economic analytics to improve economic forecasting and monetary and fiscal tools*
- *AI-enabled digital footprint for mobile money access*
- *AI-enabled transparent inventory management in supply chain for more efficient purchasing power*
- *AI-enabled digital support hubs for workers*
- *AI-enabled remote work platforms to mobilize contingent workforce*
- *AI, cloud, satellite and drone-enabled disaster risk insurance products (incl. parametric bonds) and microfinance*

Medium maturity

- *Community-distributed marketplaces for goods and services, incl. peer-to-peer (P2P) trading and smart contracts*
- *AI-enabled supply and demand "matchmaking" for goods and workers*
- *Community-growth-focused crypto solutions*
- *Transparent monitoring and management of forced labour, modern slavery and human trafficking harnessing blockchain*
- *Transparent and immutable records of workers' rights and compensation*

Low maturity

- *Robotic exoskeletons to assist in manual/physically exhaustive tasks*

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

High maturity

- *Robotics for manufacturing and construction process automation*
- *Smart IoT-enabled infrastructure for efficiency and maintenance*
- *Drones and robotics for remote goods delivery and remote infrastructure maintenance*
- *IoT-enabled tracking and optimization of industrial machinery*
- *Next-gen satellite, drone and AI-enabled geospatial mapping and AR/VR visualization for infrastructure planning and development*

Medium maturity

- *Blockchain-enabled value chain monitoring and provenance tracking of materials*
- *Automated, 3D-printed buildings and infrastructure*
- *3D-printed optimized product design and intelligent packaging*
- *AI and robotics for precision-strength capabilities and waste prevention*
- *Blockchain-enabled circularity and sharing business model incentives, e.g. tokenization to encourage collection and recycling of waste*
- *4IR-enabled internet connectivity in rural locations (drones, satellites)*
- *Autonomous and connected mobility solutions for efficiency and systems optimization*

Low maturity

- *AI-enabled discovery fuelling industrial R&D and innovation; quantum-enabled discovery*
- *Advanced materials for sustainable and durable infrastructure*

Source: PwC Research

Table 1 (cont. p4 of 6): Prominent Fourth Industrial Revolution-enabled applications for Global Goals 1–16, and their maturity

10 Reduced Inequalities

High maturity

- *AI-enabled digital footprint for mobile money access*
- *AI and satellite/drone-enabled next-gen disaster risk insurance products (incl. parametric bonds) and microfinance*
- *Next-gen demographics data analytics*
- *AI-enabled platform collating information on social services and policies*

Medium maturity

- *AI for unbiased selection to support inclusivity, e.g. for access to public services*
- *Community-distributed marketplaces for goods and services, incl. peer-to-peer (P2P) trading and smart contracts to facilitate inclusion*
- *Inclusion-orientated and community-focused cryptocurrency solutions (e.g. Brixton pound)*
- *AI-enabled cyberabuse and diversity and inclusion discrimination detection and mitigation*
- *Blockchain-enabled digital voting*
- *Blockchain-powered digital identity to enable access to services, incl. for refugees*
- *AI-based real-time tax structures and tax-recovery optimization*

Low maturity

- *4IR improved living conditions for disability groups, e.g. AI sensory augmentation, robotic exoskeletons*
- *Autonomous cars, built with universal design principles, for people unable to drive*

11 Sustainable Cities and Communities

High maturity

- *Sensor-based grid and AI-based urban network management (pollution, waste, water, energy)*
- *Next-gen satellite, drone and IoT land-use detection and management*
- *AI-, VR/AR-optimized city design and planning*
- *4IR-enabled building-management systems*

Medium maturity

- *AI-enabled urban mobility management, including autonomous EVs (e.g. traffic lights, optimal route mapping to relieve congestion/emissions)*
- *Urban greening infrastructure (e.g. living buildings, pollution sequestration, graphene-based self-cleaning concrete)*
- *3D-printed buildings and infrastructure*
- *AI-enabled supply and demand prediction with blockchain-powered purchasing for logistics*
- *4IR-enabled decentralized, peer-to-peer community energy and water grids incl. AI, IoT and blockchain*
- *AI-led disaster prediction (automatic thresholds enabling early evacuation warning)*
- *Drones for remote community goods delivery including disaster relief supplies*

Low maturity

- *Advanced construction materials (e.g. low/zero emissions steel and aluminium, zero/negative emissions concrete)*
- *Building level electricity and thermal storage and conversion via advanced materials (e.g. graphene)*

12 Responsible Consumption and Production

High maturity

- *AI-enabled supply chain process optimization and automation*
- *AI-optimized logistics and distribution networks to minimize costs, emissions and waste*
- *Digital twins for lifespan performance optimization*
- *4IR optimization of industrial machinery, manufacturing and recycling, incl. robotics for sorting and recycling*
- *AI- and IoT-enabled consumption and production data analytics*

Medium maturity

- *Local 3D-printed products and intelligent packing to minimize distribution-related emissions*
- *Community-distributed marketplaces for goods and services, incl. peer-to-peer (P2P) trading and smart contracts*
- *Advanced biodegradability solutions for products/materials*
- *AI- and blockchain-enabled data platforms for monitoring and managing sustainable trade*
- *4IR-technology to eliminate waste in food and fibre value chains*
- *Blockchain-enabled value chain monitoring and provenance tracking*
- *AI- and blockchain-enabled life cycle traceability to aid responsible purchasing decisions*
- *Blockchain-enabled incentive schemes for circular/recycling outcomes*
- *Advanced materials for low emissions chemicals, steel and aluminium*

Source: PwC Research

Table 1 (cont. p5 of 6): Prominent Fourth Industrial Revolution-enabled applications for Global Goals 1–16, and their maturity

13 Climate Action

High maturity

- *Smart and transparent land-use management*
- *Precision analytics for agricultural management*
- *Autonomous and connected electric vehicles*
- *Earth management big data platform e.g. monitoring carbon emissions*
- *4IR-enabled building-management systems*
- *Smart and connected city planning and mobility systems*
- *Large-scale AI-/drone-enabled precision reforestation*
- *4IR-enabled decentralized clean energy grids*
- *Low-cost, low-GHG synthetic proteins*

Medium maturity

- *4IR technology to eliminate waste in food and fibre value chains*
- *Advanced battery storage technologies*
- *Advanced materials for clean energy generation and transmission (e.g. semiconductors, solar coatings)*
- *4IR-enabled next-gen weather and climate prediction and response analytics*
- *Advanced materials for low/zero emissions aluminium, steel and cement*
- *Tech solutions that reduce the need for travel, e.g. 3D printing of goods and (ultimately) AR/VR experiences*

Low maturity

- *Advanced materials for bio-energy carbon capture and storage (BECCS)*
- *Advanced waste heat capture/ conversion*

14 Life Below Water

High maturity

- *Habitat monitoring and analytics (e.g. monitoring pH and pollution)*
- *Marine pollution management technologies*
- *AR/VR training, information for marine industries (fishing, shipping)*

Medium maturity

- *AI-enabled data platforms to monitor and manage fishing activity and compliance*
- *Robotics for fishery process automation*
- *Fishery stock forecasting (e.g. automated fish catch thresholds)*
- *Platform for managing biological assets e.g. fishing and shipping, incl. IoT, AI analytics and blockchain*
- *Autonomous vessels and connected sensors for automated ocean health mapping*
- *Alternative financing mechanisms for sustainable fisheries and ocean conservation (e.g. cryptocurrency, mobile money, reward platforms, and microfinance)*

Low maturity

- *Coral genome modification to aid resilience (synthetic biology)*
- *Attracting and removing micropollutants (synthetic biology)*
- *3D-printed coral reef structure for marine restoration*

15 Life on Land

High maturity

- *Real-time habitat and land-use mapping, monitoring and detection of illegal or adverse activities*
- *AI-/drone-enabled precision habitat restoration and precision reforestation*
- *Autonomous vehicles and drones for planting and feeding*
- *4IR-enabled wildlife tracking, monitoring, analytics and pattern forecasting and real-time detection, e.g. disease, animal capture*

Medium maturity

- *Earth management big data platform, e.g. endangered species dashboard and rights codification*
- *AI simulation of animal, plant and habitat interaction*
- *AI-assisted plant and animal disease identification and detection*
- *Alternative conservation financing mechanisms, e.g. cryptocurrency, mobile money and microfinance*

Low maturity

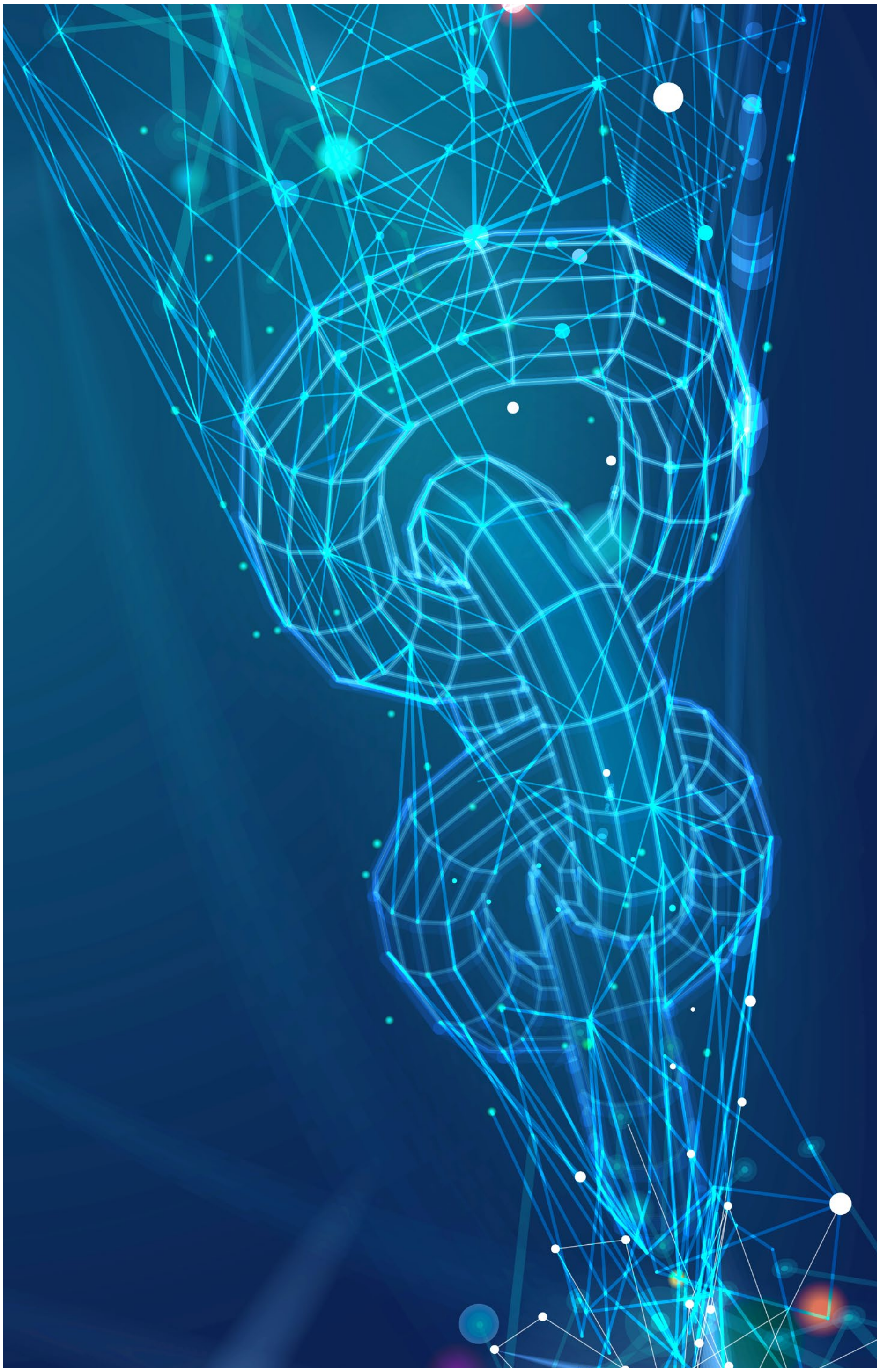
- *AI-enabled genome sequencing to optimize conservation efforts*
- *Genetic rescue for endangered and extinct species*
- *Robotics to control the spread of invasive species, e.g. identify and extract invasive species in a stream*

Source: PwC Research

Table 1 (cont. p6 of 6): Prominent Fourth Industrial Revolution-enabled applications for Global Goals 1–16, and their maturity

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

High maturity
AI-enabled IoT devices for emergency response
Low-cost biometric identification for the last mile
AI-enabled digital passport and visas for border security
AI-enabled identity tax fraud identification (using browsing data, retail data and payments history)
AI-enabled cybersecurity systems
Real-time natural language processing to analyse public sentiment to inform policy
Medium maturity
AI- and computer vision-enabled public services (e.g. tracking and sentencing of criminals and unbiased policing, identification of missing persons)
AI-enabled corruption-reporting platforms
Traceable and immutable record of public spending and supply chains harnessing blockchain
Blockchain-enabled crowd-finance for litigation, including for SMEs and marginalized groups
Blockchain and AI-enabled "fake-news" verification
Blockchain-enabled digital voting
AI-enabled cyberabuse and discrimination detection and mitigation
Blockchain-enabled citizen loyalty and reward platforms



Source: PwC Research

Fourth Industrial Revolution-enabled moonshot innovations for the Global Goals

In addition to the prominent present-day Fourth Industrial Revolution applications for the Global Goals identified in Table 1, there are a number of Fourth Industrial Revolution-enabled game changers “in vitro” (e.g. in R&D phase) that, if cracked, could provide a step-change in achieving specific goals. These so-called Fourth Industrial Revolution-enabled Global Goal “moonshots” are presented in Table 2.

Each so-called “moonshot” has been highlighted here on the basis that it represents a credible Fourth Industrial Revolution-enabled innovation at concept stage (or prototype at most) that has the potential for considerable impact on a specific Goal or Goals, and for which there is hope that, with significant leadership and focused investment, the solution could be achievable in the next five to 10 years (i.e. before 2030). The moonshots selected must satisfy the characteristics of: transformational impact (i.e. the solution directly addresses the priority challenge areas underlying the goal(s) and could disrupt current approaches); adoption potential (i.e. the potential population size is large); and technology centrality (i.e. Fourth Industrial Revolution technology is a vital cog in the solution).

These moonshots are more aspirational and risky, and may only achieve scale of deployment post-2030 in some cases. However, as they could have a material impact on the challenges underpinning certain Goals if successfully deployed at scale. We highlight them here in an effort both to focus entrepreneurs on “grand tech-challenges for the Global Goals” and to focus public and private R&D efforts over the coming decade. The list in Table 2 is not exhaustive, but rather illustrative of 20 critical moonshots where scaled-up R&D effort and collaboration is needed. We also note that, practically, such R&D bets will require an enabling infrastructure, including universities with multidisciplinary talent across tech and sector/domain areas, investment in and connection of entrepreneurial ecosystems and financing including innovation finance mechanisms (see Chapter 4).

Table 2: Fourth Industrial Revolution-enabled moonshots for the Global Goals

THE MOONSHOTS

7, 13	*Quantum-computing-determined optimal carbon capture material*	*Ultra-high-speed, zero-emissions long-haul transport, including underground, surface, aviation, shipping and drones*	7, 9, 11, 13
7, 13	*4IR-enabled deployable nuclear fusion using AI to predict disruptions that halt feasibility*	*Zero-waste advanced materials for clean energy and advanced waste heat capture and conversion*	7, 9, 11, 12, 13
2, 13, 14	*Advanced materials for generation of low-cost and zero-emissions gaseous fuels, incl. ammonia and hydrogen*	*Quantum-enabled extreme efficiency data centres and supercomputers*	7, 9, 12, 13
14, 15	*Genetic rescue and genome modification for endangered and extinct species and resilience*	*4IR-enabled internet connectivity for all (drones, satellites)*	1, 4, 5, 8, 9, 10, 11
6, 11, 13, 14, 15	*Attracting and removing micropollutants (synthetic biology)*	*Quantum cryptography for the prevention of cyberattacks on AI/ quantum computers*	9, 16
3, 6, 13	*Low-zero emissions and ultra-low-cost desalination technology using advanced materials*	*AI-enabled privacy-protected, public good digital health platform collating healthcare data, sensors, wearables and genomic data*	3, 16
2, 12, 13, 15	*End-to-end automated, connected and optimized food and fibre system, incl. elimination of spoilage, loss and waste*	*AI-enabled development of new antibiotics to address microbial resistance to current antibiotics*	3, 10
11, 12, 13, 15	*Low-cost, low-GHG emissions synthetic proteins (AI and synthetic biology)*	*4IR-enabled “access to care” digital technologies, distribution and delivery systems*	3, 10
2, 9, 12, 13	*Advanced materials for durability of energy-intensive products and materials*	*Decoding well-being and longevity using AI and sensors for personalized health maps and sequenced genomes and phenotypic data*	3, 10
11, 12, 13	*Zero-emissions chemicals, steel, aluminium, cement using advanced materials and/or biotech (e.g. biocement)*	*Gene editing (e.g. CRISPR) to tackle human diseases driven by gene mutation*	3

Source: PwC Research

Five transformative changes enabled by the Fourth Industrial Revolution that are key to tackling the Global Goals

Transformative outcomes enabled by the Fourth Industrial Revolution
Productivity of systems
Transparency, traceability and accountability
Decentralization and access
Creation of, and access to, new financing models
Discovery, including new materials

1. Productivity of systems

AI, in particular, brings with it an ability to optimize systems through automating, assisting, augmenting and ultimately creating autonomous systems to execute decision-making without human intervention. In some cases, productivity gains result from optimizing use of inputs as new AI tools enable more precise monitoring and control of the production process, boosting output and creating opportunities for cost and raw material savings. For example, precision monitoring in agriculture can enable savings of specific inputs such as fertilizers and water used for irrigation, and AI levers in the water sector alone could also boost global GDP by $190 billion by 2030.[33] Higher output productivity can also arise from connected processes that produce greater output for a given set of inputs, for example, AI-enabled smart grids that maximize operational efficiency by optimizing distribution across multiple energy sources on localized grids. Finally, automation of manual and routine tasks in given sectors can increase the efficiency of the labour force. For instance, the use of autonomous deliveries and agricultural robotics can boost labour productivity in the sectors and free up workers to focus on more value-adding work that can boost higher household incomes. Labour task-automation, in parallel, will require reskilling and social safety nets to minimize the risk of widening inequality.

Example: Connected, autonomous vehicles

Autonomous vehicles (AVs), enabled by sensors, big data and AI, can operate and navigate with reduced or no human control and are rapidly moving from the R&D phase to trial and deployment. These technologies are poised to transform not just the future of short-haul transport but also agriculture (e.g. autonomous tractors and harvesting), healthcare (e.g. autonomous ambulances), mobility and the urban landscape and more broadly infrastructure and employment. Connected and autonomous mobility is expected to be particularly transformational in the urban environment. AI-enabled automation of mobility will improve efficiency of transport networks through route optimization, eco-driving algorithms that prioritize energy efficiency and automation of ride sharing, delivery and logistics services. However, the transition to connected autonomous fleets in cities will be gradual, and it may be decades before fully autonomous urban fleets are the norm. While full "Level 5" AVs (with no human intervention) may still be decades away, "Level 4" AVs (highly automated, but with driver takeover when needed) prototypes are beginning to be tested. At this level, once fully deployable cars can drive in cities and provide mobility-on-demand services, more substantial emission-reduction benefits also begin to appear. Estimates for the United States predict efficiency increases will result in reduced emissions of CO2 and harmful particulates by up to 60%.[34]

2. Transparency, traceability and accountability

There is currently growing pressure from citizens, investors, corporations and regulators for increased transparency and accountability about environmental and social risks and/or impact, including corruption, human rights violations, modern slavery, gender-based violence, water security, GHG emissions and nature loss. Where regulations do exist, compliance is often limited by the availability of data, as global supply chains in particular are often complex and opaque. Such provenance, traceability and transparency of environmental and social impact is also critical to business management in a broader sense – from improving enterprise-risk management practices to enabling corporate disclosure and reporting. Fourth Industrial Revolution technologies are rapidly enabling more accessible and close-to-real-time tracking and monitoring of global supply chains, and more broadly of human activities on the Earth's surface. Harnessing AI, IoT, drones and advanced satellites, and blockchain, digital platforms enable transparency of systems, transforming the way they can be monitored and managed. This includes applications related to "see-through" supply chains (see below), real-time transparent sustainability monitoring (Goal 13), reporting and verification (Goals 16, 17), Earth and/or resource-management platforms (Goals 2, 6, 7, 13, 14, 15), accountable carbon markets and traceable sources of sustainable finance to tackle climate change (Goal 13).

Example: "See-through" supply chains

Blockchain platforms are increasingly being used to record transactions using supply-chain data and enable full traceability of provenance (e.g. origin), offering the potential for traceability from source to store. This can build confidence in legitimate compliant operations, expose illegal or unethical market trading or activities, mitigate quality or safety problems, reduce administrative costs, enable greater access to finance, improve monitoring, verification and reporting, and potentially help avoid litigation. As these solutions become more mainstream, they will likely push organizations to be accountable for their actions, and enable more informed responsible investing practices. As an example, in the Democratic Republic of the Congo (DRC), which produces around 58%[35] *of the world's cobalt, human rights issues have been associated with cobalt mines and smelters, with leading manufacturers sourcing the metal elsewhere. This is damaging the DRC's economy. Rather than withdrawing from the DRC, Cobalt Blockchain*[36] *is developing a blockchain platform that traces mineral provenance from its source. This allows for identification of malpractice within a supply chain,* *and provides downstream manufacturers with confidence in supply decisions, ensuring ethical sourcing.*

3. Decentralization and access

Decentralized systems distribute information and authority across a network. AI combined with technologies such as the IoT, blockchain and sensors can offer smart monitoring and active management of resources, including physical resources such as energy and water, financial resources and data (e.g. health information). Decentralized systems can also provide a platform for peer-to-peer trading of resources and services. Alongside these advances, 3D printing enables localized production, facilitating decentralization, though it requires a systemic shift from exchanging physical products to exchanging digital prints. Decentralization can help progress the Global Goals, providing both environmental and social benefits – reducing GHG emissions from clean distributed energy sources (Goal 13), increasing resilience and efficiency of resource distribution and management systems (Goals 12, 15) and promoting inclusivity (Goals 5, 10).

Example: Decentralized and sustainable resource management

Centralized utility systems can often struggle to match supply and demand optimally, are prone to single points of failure and suffer from distribution losses and leaks across a network. For energy, decarbonization of the power sector also relies on the emergence of distributed renewable energy sources. Blockchain, combined with AI and IoT, could initiate a fundamental transition to global decentralized utility systems. Platforms could collate distributed data on resources (e.g. household-level water and energy data from smart sensors) to end the current asymmetry of information that exists between stakeholders, peer-to-peer transactions, dynamic pricing and optimal demand-supply balancing. It would reduce intermediaries, make systems more efficient, cost-effective and resilient, and increase local sharing of resources to bolster their efficient use, which in turn will make distributed models more attractive.

Example: Peer-to-peer sharing platforms

The sharing economy has the potential to reach around $335 billion of global revenues by 2025[37] – there had been a particularly large increase in car, office and house sharing. AI, combined with online platforms, is accelerating the potential of the sharing economy – for example, by optimizing the matching of customers with listings, price setting and detecting and eliminating fraud and misinformation. A study by the World Economic Forum and MIT revealed that during the 2016 Olympics in Rio, Airbnb housed 85,000 of the city's estimated 500,000 visitors.[38] P2P platforms enable anyone, even in the most remote locations with basic mobile infrastructure, to gain market access – this holds enormous potential for the advancement of social inclusion.

4. Creation of, and access to, new financing models

The UN estimates that there is a funding gap of $5 trillion to $7 trillion per year to meet the Global Goals, with an investment gap in developing countries of about $2.5 trillion.[39] Fourth Industrial Revolution-enabled finance platforms, products and services could potentially revolutionize access to capital and insurance, and the ability of billions of individuals in marginalized groups to transact payments and participate in the digital economy (e.g. mobile money architecture currently processes more than $1.3 billion a day.)[40] Fourth Industrial Revolution technologies are also emerging that democratize investment by enabling crowdsourcing and new investors in projects that address environmental and development challenges – from retail-level investment in green infrastructure projects through to charitable donations for developing countries. As an example, the Sun Exchange launched a blockchain-based platform for crowd-selling solar assets, connecting people who want to invest in solar with those who want access to it. This enables financing of solar projects in sub-Saharan Africa, where high upfront costs and political barriers can prevent financing from traditional investment-capital sources, which inhibits widespread deployment.

Example: AI-financial profiling and credit scoring

One of the biggest barriers to financial inclusion for many individuals and businesses in developing economies is their inability to demonstrate a formal credit history – 1.7 billion adults still lack access to financial services.[41] Machine-learning algorithms that use non-traditional sources of data, such as mobile phone activity and other digital footprints, to evaluate creditworthiness are starting to be used and have the potential to address mass exclusion from financial services. For example, Aire[42] is using virtual interviews and machine learning to create personalized credit scores based on data such as financial maturity, career and lifestyle.

5. Discovery, including new materials

As well as advancing existing systems, achieving the scale of transformation needed for many of the Goals relies on the discovery of new solutions – from new insight to new materials – that fundamentally change the way we do things. A vital characteristic of AI is that it automates and speeds up discovery, whether that is through unsupervised learning techniques that develop an intelligence that humans don't have yet (e.g. DeepMind's AlphaGo Zero) or the ability of machine learning to enable big data-driven discovery and speed up experimental validation. The implications of AI-enabled discovery, coupled with other new technologies such as advanced materials and biomaterials, can be profound. They can, for example, accelerate the discovery of clean fuels (Goals 7, 13), the discovery of new antibiotics (Goal 3) or biotechnology breakthroughs for clean water (Goal 6).

Example: Synthetic and cultured proteins

Synthetic biology involves the chemical synthesis of DNA to produce biological components that do not exist in the natural world. These include advanced biofuels, renewable chemicals and synthetic meat. Cell cultivation is the process of cultivating cells in vitro – such as cultivated meats made from animal cells. Technology, including AI, is fundamental to improving the speed, precision and cost of these processes. The US-based firm Beyond Meat, for example, which makes vegan "meat" out of pea protein isolate, floated in 2019 and has been valued at around $3.8 billion.

Chapter 3: Barriers to scaling and the risks of getting it wrong

Barriers

The opportunities that new technologies bring in achieving the Global Goals are both sizable and significant. For their full potential to be realized some important barriers will need to be overcome. Scaling these new technology solutions will also create a range of risks that need to be carefully managed.

Through our analysis of over 300 existing and emerging Fourth Industrial Revolution applications relevant to advancing the Global Goals, we identified and uncovered a number of important barriers and risks. Understanding these fundamental challenges and proactively addressing and managing them will be essential to unlock the promise of the Fourth Industrial Revolution for the Global Goals.

Overview of barriers
Data Limited data volume quality, analysis and interoperability
Technology Wide variation in maturity of emerging technologies, insufficient infrastructure to support them and a lack of relevance to certain contexts
People Unequal skills and capacity distribution and insufficient collaboration
Process Rigid and insufficient regulatory frameworks and a lack of investment

Data

Data is critical for the development and correct deployment of technology. Particularly with AI, we are doing more with data than ever before: unlocking insight that can optimize systems or generate breakthrough discoveries to help tackle the Global Goals. Yet the true value of data is often unrealized and data-access barriers are numerous, and were identified in our research as a significant bottleneck to scaling innovations. As the Global Partnership on Sustainable Development Data notes, "access to data remains a great challenge due to real or perceived barriers".[43]

Public-private business models for data collaboration remain a challenge. On the positive side, corporations are increasingly seeing the commercial benefits of data collaborations: From 2017 to 2019, the number of companies forming data-related partnerships rose from 21% to 40%.[44] Data collaboratives across stakeholder groups are growing in the context of environmental and humanitarian development challenges, but nowhere near the volume needed to unlock the full value these partnerships could represent for society. In many cases, an important barrier to scaling lies in the need to identify a sustainable economic model to ensure the continued provision of data and insights because goodwill on "data philanthropy" often has a life expectancy. Blended-finance, payment-by-outcome or freemium- business models are options.[45]

Despite the volume of data globally increasing rapidly – 2.5 quintillion bytes of data is produced per day and 90% of all data was created in the past two years[46] – data volume remains an important challenge across certain Goals, and across low-income geographies and among vulnerable demographics. These gaps are predominantly caused by a lack of capacity to collect data, unclear data ownership structures and a lack of commercial incentive to obtain or share data. Data quality, for instance, related to incomplete or outdated data, often also inhibits value creation and stems from inconsistent data governance and measurement mechanisms across geographies and organizations. Finally, the integration and exchange of data sources across systems and platforms is also a critical barrier. This typically relates to differing methodologies and data standards, which affects and limits uptake.

Case study: Diagnosis and treatment of skin cancer – Goal 3

About 70% of cancer deaths occur in low- and middle-income countries. An AI-enabled smartphone application, using convolutional neural networks (CNNs), has been developed for skin cancer detection from images. This could dramatically increase access to diagnosis of skin lesions such as melanomas in the early stages of development, particularly in underserved, rural areas.

Rather than the technology itself, a primary obstacle to the development of this application is data volume, quality and interoperability. Large datasets are required to ensure accuracy of diagnosis and often this data is closed and restricted to a small number of players. There are also ethical implications that arise from this lack of data – research has shown that there are fewer images of melanoma on darker skin, creating bias within any AI that is trained due to a limited dataset potentially exacerbating racial disparities.[47]

From our assessment we have identified more than 10 other technology applications in development that use CNN for diagnosis. These include the diagnosis of other diseases in humans, such as psoriasis and seborrhoeic keratosis, and also examples of automatic identification of crop disease – increasing food security and enabling more sustainable agricultural practices (Goal 2).

Technology

Technology solution maturity

Technology maturity varies greatly between technologies, across different Global Goals, from country to country and even within borders. Across the database of applications studied, there was a substantial deviation in maturity of the technology solutions being applied today, both across and within the Global Goals. Reasons included different levels of investment in R&D and research infrastructure across countries, digital-infrastructure readiness, the commerciality of the solution concerned, government incentives and the maturity of the underlying core technologies.

Geographically, unsurprisingly, use cases dominate in countries with high levels of innovation, R&D expenditure and government incentives. For example, China has one of the highest levels of patent applications in emerging technology, and is responsible for 73% of AI and 32% of blockchain patent fillings. This level can be contributed to government incentives that encourage emerging technology patents. Across the Goals, the highest maturity of mapped technology applications is found in Goal 7 (Clean Energy). This is largely associated with the market and regulatory incentives to drive energy access, decarbonization and digitization of the energy sector. For example, AI- and IoT-enabled predictive maintenance of energy infrastructure both drives optimization of power generation and reduces costs, creating a strong market incentive for investment. In contrast, for Goal 14 (Life Below Water), the impact potential of new technology applications is high, but a lower level of solution maturity was found. This is reflective of lower investment in R&D and solution development, across a less commercialized challenge area.

Technology infrastructure

In areas where infrastructure to support digital and other Fourth Industrial Revolution technologies is either underdeveloped or non-existent, implementation of new technological solutions is a lot more challenging. Our analysis of Fourth Industrial Revolution applications for the Global Goals demonstrates the criticality of basic infrastructure – specifically cloud and internet access, and electricity as the foundational infrastructure for the digital age.

Cloud and internet access

More than 80% of the technology applications identified across the Goals rely on internet access

Electricity access

More than 90% of the technology applications identified across the Goals rely on electricity access

Least-developed countries (LDCs) often lack access to basic internet and electricity infrastructure. Africa has an internet penetration rate of just under 40%,[48] and 800 million people lack access to electricity.[49] Broadband availability in particular, and its ability to provide high-speed access to the cloud, is critical to Fourth Industrial Revolution solutions that underpin the future of agriculture, medicine and education, such as precision farming, telemedicine and online education respectively. This suggests that the idea that the Fourth Industrial Revolution can support rapid leapfrogging is highly dependent upon countries catching up on both digital and physical infrastructure. Even in a future with more "at the edge" computing intelligence, high-speed access to the cloud is essential to access and scale these Fourth Industrial Revolution solutions. It is therefore not surprising that, since 2018, less than 1% of estimated global public cloud services revenue was generated in Africa.[50] The broadband gap is not only a developing world issue; roughly 113 million Americans, many in rural communities, do not have broadband access at home.[51]

The public sector has an important role to play in closing the broadband gap alongside, and in partnership with, technology and telecommunications companies. This includes regulatory reforms to drive investment and competition, and supporting new technology alternatives to expensive fibre-optic cables, including airband and satellite-based Wi-Fi approaches to reduce initial capital and

operating costs that are particularly relevant to underserved rural communities. Matched capital investments by companies and governments will be important, alongside private-led efforts such as Microsoft's Airband programme to bring broadband to 2 million people.[52]

Technology relevance

Technology advancement is currently driven by companies headquartered predominantly in advanced economies. Deployment of technology solutions does not always happen where the need is greatest, particularly across some of the social Goals. In global terms, 90% of AI start-ups are based in the United States[53] and most AI-related patents are registered there.[54] In addition, venture capital funds invest in emerging, early-stage firms – typically start-ups that have developed innovative business models or technologies. Between 2008 and 2017, most global VC investment flowed into the United States ($694 billion); the total VC flows to emerging markets (excluding China and India) was just $24 billion.[55] From a gender lens, globally only 22% of AI professionals are women, compared to 78% who are men.[56]

This evidence suggests that it is likely that a large proportion of advanced technology applications are being developed by men in advanced economies, which poses questions as to the relevance of the technology for those using it, particularly for women in LDCs. This insight was also reflected in our assessment of advanced technology applications. We found only a few applications that directly responded to Goal 5 (Gender Equality), and those that were identified were of low maturity. Further analysis found that for Goal 6 (Clean Water and Sanitation), around 70% of applications found to respond to water scarcity were developed in the United States – with only a handful in sub-Saharan Africa, which suffers from the highest levels of water stress globally.[57]

Case study: Voice recognition – gender and race bias

More than 5% of the applications identified rely on voice-recognition technology. Some applications include digital assistance, advanced security, real-time translation, efficient transport and disability support (including for visual impairment).

Voice or speaker recognition relies on machine learning to receive and interpret dictation. The accuracy of voice recognition differs according to gender and dialect – it is 13% more accurate for men, and certain dialects, such as Indian English, have only a 78% accuracy rate.[58] This bias exists because of the way computer scientists have collected, prepared and programmed data.

Why does this matter? As voice recognition becomes progressively more powerful, the potential for social injustice could continue to grow – affecting the potential progress towards Global Goals – specifically Goal 5 (Gender Equality) and Goal 10 (Reduced Inequalities). If harnessed in the right way, however, voice-recognition technology has significant potential to advance the Global Goals.

People

The talent gap: upskilling and reskilling

Rapid advances in technology development and adoption requires significant human skills and institutional expertise. The current pool of individuals with this expertise is too small and unequal to develop the correct technology at scale. This is driven by changing labour markets, evolving demands for reskilling and upskilling and a workforce undergoing structural change. A lack of access to education, insufficient funding for training and a paucity of available training and courses for digital skills further exacerbates this issue. It is estimated that it will take an investment of $19.9 billion for the US government to reskill 77% of workers expected to be displaced by technology.[59]

Figure 4: Top 50 computer science degrees globally[60]

US	23	Hong Kong	3
Europe	12	Singapore	2
Canada	4	South Korea	2
China	4		

Many new technologies, including AI, require significant technology expertise and tools. An estimated 44% of companies lack access to skilled talent to adopt their AI strategy fully.[61] Furthermore, if citizens do not have access to the correct expertise or to tools, then they will find it harder to create and scale their ideas into tech solutions and scalable start-ups. Third-party AI software costs up to approximately $40,000 per year and custom AI solutions cost anywhere from $6,000 to more than $300,000. Complexity, cost and control of tools is a concern, which currently limits citizen developer access. As a result, powerful and transformative emerging technologies, such as AI, are not in the hands of many start-ups, academics, NGOs, civil society and wider interested stakeholders.

Collaboration and interdisciplinary working

Tackling global challenges requires a pool of technical and subject-matter expertise. As an example, cancer research has become highly multidisciplinary – expanding beyond the realms of clinicians and molecular biologists to include computational biologists, chemical engineers and ethicists. Yet silos are still prominent and fail to respond to the interconnected nature of the Global Goals and emerging technologies – often requiring technologists, environmentalists, businesses, government and civil society to work together collaboratively as one multidisciplinary team. Historically, silos have often formed and grown across business – as well as academia and government – due to distributed ownership of cross-business processes, geographic dispersion and division within the knowledge economy. Such isolation has typically become ingrained in working relationships and organizational cultures. Currently, more than 55% of companies work in silos and three-fifths of companies say the solution to reaching their strategic goals is collaborating more across functions.[62]

Process

Regulatory environment

Rapid technological advancements are regularly, and increasingly, outpacing governance and regulation. A fragile balance needs to be struck between ensuring that risks (and unintended consequences) are properly managed and that innovations are not discouraged that could ultimately benefit our economy, environment and society. There are four pressing challenges that regulators now face:

1. **Complexity of impact:** Traditional governance struggles to account for the complex nature of Fourth Industrial Revolution technological advancement, and its disruptive impacts across and within sectors and geographies.[63] For instance, digitalization creates a blurring of traditional distinctions between and within sectors. In terms of energy, as decentralized energy production becomes more dominant in the market, there are more and more prosumers – obscuring the distinction between consumer and producer that is typically set apart in regulation.[64]

2. **Speed of change:** The fast-paced advances in Fourth Industrial Revolution technologies and their related business models often clash with the more rigorous, thorough and slow-paced nature of policy and regulation. This means that traditional regulatory frameworks and processes struggle to stay relevant, causing incidents of slowing innovation or direct negative societal ramifications (e.g. the WannaCry incident, the Cambridge Analytica controversy). There is a strong case for governments to develop an agility in the regulatory space in a way that mirrors the agility in innovation in the tech sector itself – e.g. the adoption of limited rules akin to a "minimum viable product" and the incremental development of new regulatory provisions that learn from experience. Examples of iterative and agile approaches are emerging, including ASEAN governments moving away from red-taping industry with stringent regulations in favour of voluntary standards to open up testing. For instance, the self-regulatory Subscription Video-on-Demand Industry Content Code in ASEAN was developed by subscription video-on-demand (SVOD) services operating in South-East Asia.[65]

3. **Enforcement potential:** The decentralized and digitalized nature of many emerging technology applications increases the complexity of legal liability, making it a lot harder to attribute liability to a specific individual or corporation. For example, with blockchain technology, it is often unclear who should be held accountable and this will depend on the nature of the blockchain's use, who is running it and how it functions (this is particularly the case for decentralized autonomous organizations, or DAOs).[66] Considering blockchain was identified as central to more than 25% of the top technology applications in our analysis, this will be a critical consideration when looking to accelerate technology to tackle the Global Goals.

4. **Transboundary nature:** The distributed and networked nature of many Fourth Industrial Revolution technologies often falls outside specific jurisdictions. This means it is unclear under which jurisdiction certain transactions fall – creating complex, duplicative and, at worst, conflicting regulatory and compliance demands for entities and individuals. Bitcoin is a good example of this – its regulation differs widely between jurisdictions. For example, it is completely prohibited in Algeria and Bolivia, partly restricted in China and completely unregulated by most other financial authorities who do not consider it a currency.[67]

Investment models and business incentives

The UN estimates that there is a funding gap of $5 trillion to $7 trillion per year to meet the Global Goals, with an annual investment gap in developing countries of about $2.5 trillion.[68] This investment gap and inadequate financing models across some of the global challenge areas less directly linked to private-sector markets, or in more challenging geographies, prevents maturation and scaling of solutions. Some significant barriers to investment include:

1. **Inadequate finance infrastructure:** Traditional finance has a strong focus on centralized and often capital-intensive infrastructure. Digital and decentralized technologies, however, sometimes require a different financing model. This is because typically the consumer can choose from multiple providers, which results in uncertainty of payback. Digital assets also tend to be smaller and more geographically dispersed, making asset management more complex. Financial tools and structures have not fully adapted to the needs of decentralized and distributed emerging technologies. There is currently a lack of the innovative public, private and blended investment arrangements that are often required to scale the right Fourth Industrial Revolution-supportive digital infrastructure in order to scale these new technology solutions.

2. **Lack of a clear business case for investment:** Across a number of the Global Goals, the short-term return on investment is low where benefits are largely externalities to current markets and/or considered more broadly as public goods.

3. **Higher risk of investment:** Many of the technology solutions identified are high risk due to either being unproven at scale or because the underlying technology is rapidly changing – assets can quickly become obsolete. This is particularly apparent where solutions are public sector-led and/or regulated, and where infrastructure considerations can be complex (e.g. within primary sectors such as agriculture and water). Many governments are not doing enough to lower the cost and de-risk capital investments into frontier technological innovations.

4. **A lack of incentives:** Our assessment identified that Goals 1, 5, 14 and 15 have the lowest number of applications identified. Further analysis of specific technology applications under these Global Goals revealed that, for particular social ventures, particularly those tied to public goods, there is only an embryonic market.

Risks of scaling technology

For all of the enormous potential that scaling Fourth Industrial Revolution technologies offer for accelerating action to reach the Global Goals, these technologies also have the potential to exacerbate many existing societal challenges, and to create new risks that could hinder the Global Goals. There are two broad areas: first, risks that are inherent in the characteristics of new technologies being designed and developed and, second, risks in how those applications or solutions are deployed.

Here we highlight some of the prominent risks associated with Fourth Industrial Revolution applications, specifically related to how they may hinder societal, developmental and environmental progress.

Table 3: Key risks of scaling technology

Performance design risks	
Bias	Inherent bias in technology design and development may perpetuate and exacerbate existing racial and gender discrimination, cultural prejudices and inequalities. *Example: Racial and gender bias in AI-based social assessment tools.*
Uncertainty and errors	Advanced systems are also prone to errors – for instance, where historic data trends are used to make future predictions. *Example: Natural disaster early-warning systems that rely on historical data in a changing climate.*

Socioeconomic risks	
Job displacement	Changing job requirements and potential job displacement across some sectors and certain geographies, as well as the evolving demands for reskilling and upskilling a workforce that is undergoing rapid structural change. Rapid shifts in the labour market could exacerbate existing inequalities. *Example: Automation of processes and job loss/change in transportation, manufacturing and agriculture.*
Concentration of power	Ubiquitous uptake of specific technologies, in combination with limited competition, drives a risk of power and algorithms becoming concentrated in a small group of individuals or within a small number of organizations. These tools and platforms are mostly in the advanced economies currently. *Example: Facebook's system processes 2.5 billion pieces of content and 500+ terabytes of data each day.*[69]

Environmental risks	
Greenhouse gas emissions	Technology solutions, including AI, blockchain, the IoT, cloud services, 5G and quantum computing can consume large amounts of energy due to the computer processing power required and the number of operations or sensors feeding into the digital system or network. Ensuring data centres and tech solutions are 100% powered by renewable energy will be crucial to minimize their environmental footprint. *Example: The environmental cost of a single bitcoin transaction is estimated to be 20,000 times greater than that of Visa.*[70]
Biodiversity loss	Left uncontrolled, technology could exacerbate resource exploitation and biodiversity loss. For instance, using AI and computer vision to optimize discovery of scarce resources. *Example: Open-source geospatial mapping used to aid targeted deforestation, identify illegal mining spots or identify fishing spots in regulated environments.*
Pollution	Electronic waste, including computers, devices and sensors, has the potential to exacerbate environmental pollution. Technology can also increase air and water pollution. By contrast, many emerging technologies (e.g. electric autonomous vehicles and AI optimization of systems) have the potential to reduce noise and air pollution. *Example: In 2021, the amount of e-waste generated is predicted to grow to 52.2 million tonnes,*[71] *with just 20% formally recycled.*

Security and control risks	
Privacy and data	Exploited data (e.g. personal data), including hacked, breached and misused data, can cause extensive reputational, economic and security damage. Sensitive information such as financial or health data could then be made accessible through porous technology systems. Deep fakes, using machine learning and large amounts of training data, can also be used to spawn misinformation. *Example: Cross-border blockchain platforms for energy or water grids stand to face significant regulatory barriers associated with data protection.*
Compromised security	Increasingly interconnected digital systems and devices, and the proliferation of “easy-to-use” decentralized technologies (e.g. sensors, drones, blockchain), have led to a growing number of cyberattacks on supposedly secure systems and decentralized terror attacks. *Example: A cyberattack on a single cloud provider could cause $50 billion to $120 billion of economic damage – an economic loss comparable to somewhere between Hurricane Sandy and Hurricane Katrina.*[72]

Chapter 4: Enabling Tech for Good

A gearshift is urgently needed, from the current race to deploy new technologies for short-term growth and private gain to a more long-sighted and principled approach that actively manages and harnesses the role technology can play for humanity and the environment.

A plethora of use cases have demonstrated how technologies can support progress on the Goals, yet a set of underlying barriers prevent the promise of "Fourth Industrial Revolution for Good" from truly being realized. A different approach is required to continually accelerate innovation and investments into breakthrough environmental and societal technology applications and to create viable markets for the scaling of these solutions over the longer term. The rapid pace of change is not expected to slow, so we must do more to manage the impact that technology has, and can have, on people and the planet.

In collaboration with the Global Future Council on Fourth Industrial Revolution for Public Goods, we have identified a set of proactive steps or so-called key "enablers" that will help to unlock the potential of technology for humankind in an assertive and timely fashion:

Figure 5: Summary of key "enablers" to harness technology for the Global Goals

Scaling 4IR for the Global Goals

Responsible technology governance

Progress development, alignment and uptake of responsible technology principles by tech firms and broader industry and a move towards adoption of a code of conduct by industry and governments.

Leadership

Leadership agenda in responsible use of technology for positive societal and environmental outcomes. Mobilize bold private- and public-sector commitments and align action agenda and coalitions of willing.

Partnerships and coalitions

Cross-industry collaboration is needed for all sectors by working together through industry bodies to work towards a harmonized set of standards.

Skills

Identification of priority skill needs (education, upskilling and reskilling) to enable 4IR for Good.

Align and combine public and corporate initiatives and commitments on skills and mobilize new commitments and partnerships for skills and talent sharing.

Public policy

Identify priority targeted policies and regulation to safeguard risks from 4IR and scale solutions for positive societal impacts.

Levers include technology policy and integrating 4IR into national and sectoral development plans and policies, public finance mechanisms to spur solutions, 4IR infrastructure investment and public procurement levers. Build capacity of policy-makers around 4IR.

Finance

Governments and public-finance institutions to back and scale technological trends to "leapfrog" traditional systems.

Levers include blended finance, government-backed incubators and accelerators and targeted patient capital.

Breakthrough innovation R&D

Define a collaborative R&D agenda that outlines priority problems and domains where tech-based innovation can be directed for maximum positive societal and environmental outcomes.

Serves as an investment framework across which R&D collaboration and investment can align.

Data and tools

Democratize data, algorithms, APIs to spur scaling of 4IR applications for public goods.

Mobilize commitments and scale initiatives to democratize assets. Progress hybrid public-private data agreements and vehicles for open data platforms.

1. Responsible technology governance: From "do no harm" to "principled and positive impact"

Rapid prototyping and scaling continues to be the operational model for success in the technology world. At the same time, given the increasing and pervasive role that technology plays, and the speed and scale of impact (e.g. AI's $15.7 trillion contribution to the global economy by 2030),[73] guardrails for technology are becoming ever more critical. Companies, governments and citizens alike increasingly recognize the need for ethical and responsible technology practices to tackle the variety of risks outlined in Chapter 3, and to build trust among a broad set of stakeholders, including company employees and board members, regulators and customers. The emergence of technology governance from industry and the public sector highlights a clear signal that the expectations for how Fourth Industrial Revolution technology is managed and used have quickly shifted. Recent examples include industry-led efforts such as Global Digital Finance's cryptocurrency code of conduct, or the Cybersecurity Tech Accord, to government-led multilateral efforts such as the EU's General Data Protection Regulation (GDPR), the G20 AI Principles and the creation of the public-private Global Partnership on AI.

The aim is not to slow down innovation - rather it is to develop sound enterprise risk management and business leadership. The opportunity is to move beyond a "do no harm" approach to one that demonstrates how this technology can actively contribute to positive social and environmental outcomes. Responsible technology governance criteria, building on those developed for responsible AI, might include:[74]

1. A robust foundation of end-to-end governance, including board-level accountability

2. Compliance with applicable regulations and laws that are also ethically sound

3. Strong performance of technology in terms of robustness, bias and fairness, interoperability and interpretability

4. Security of technology in terms of privacy, cyberthreats and rogue technology

5. Management of broader impacts (positive and negative) of technology on society, including socioeconomic impacts (including human rights, jobs, education, digital divide) and environmental impacts (climate change, nature loss, water scarcity)

6. Harnessing products and services to deliver positive social and environmental outcomes for customers

7. Purposefully creating, developing and democratizing technology applications that can address humanitarian challenges in collaboration with the public sector and third sector

8. Ensuring purposeful advocacy with policy-makers and other leading stakeholders to achieve outcomes consistent with the Global Goals

Such a principled approach enables business to anticipate issues and drive more responsible innovation, from strategy and design through to operations and monitoring. It needs to be led from the top, and embedded throughout the organization, with employee training vital to make implementation effective. This also enables governments to establish appropriate policies and regulations to ensure that the benefits of the Fourth Industrial Revolution can more effectively support positive societal outcomes. This has been seen in, for example, the case of the international standard ISO/IEC JTC 1, which serves to deliver standardization on development and implementation of AI.[75]

2. Leadership: leadership to mobilize commitments and standards

Leadership has a critical role to play. In a sector such as technology that has thrived through relatively unbridled growth, leaders will need to step up to change the current course of business and governance practices. Business is increasingly being asked to play a leadership role in tackling societal challenges expressed through new expectations from customers, employees and policy-makers. The Edelman 2019 Trust Barometer highlights that 74% of people expect their chief executive officer to explain what they have done to help society, and 64% of people want chief executive officers to take the lead on change. The past year has also seen a growing role of employee activism in the technology sector, including the need for large companies to take a more active and principled role in addressing climate change[76] concerns, to reconsider contracts with clients that result in 'unethical' application (e.g. autonomous weapons), and recognise the impact of platforms on democracy.

The public visibility of global challenges, including the climate emergency, nature loss, inequality and the Global Goals, presents an opportunity to galvanize leadership action around era-defining commitments – ones that employees, customers and citizens are already demanding from the ground up, and which require a "new chief executive officer activism". Recent examples include Microsoft's Brad Smith's leadership on AI for Good[77] and the need for assertive tech regulation;[78] Salesforce's chief executive officer Marc Benioff's leadership on issues from climate change and achieving net zero, to ocean health and privacy laws; or Amazon's Jeff Bezos making a "Climate Pledge",[79] which came after Amazon faced mounting pressure from employees to address the company's environmental impact.

Leadership-led "coalitions of the willing" can help to rally peers and build momentum around bold commitments to direct tech towards global challenges as well as building consensus on frameworks and standards to inform norms or change awareness and markets with scale and reach. However, too often collective leadership is inhibited when leaders decide not to join an initiative if they don't get to lead it, or they step away if they see another leader is in the reputational spotlight. Positive examples around Goal 13 on Climate Action include the Step Up Coalition of 25 firms with leadership commitments, Net Zero and RE100 climate-related pledges made by multiple technology firms, or the Breakthrough Energy Coalition of private investors, tech firms, industry and financial institutions collaborating to invest in decarbonization. Such leadership-led multi stakeholder groups have a particularly important role to play in the current geopolitical environment, where multilateral efforts that require consensus have been hampered by growing populism and nationalism.

Example recommendation:
A coalition of the willing of private- and public-sector leaders (chief executive officers and heads of state/ministers) who will champion bold and proactive commitments and action to steer technology towards tackling the Global Goals and enabling a sustainable Fourth Industrial Revolution. This will be a core feature of Frontier 2030: Fourth Industrial Revolution for Global Goals Platform.

3. Partnerships: collective action and collaboration

Individual leadership is necessary, but not sufficient. Collective and collaborative action across the public, private and civil society sectors is required through large partnerships, networks and coalitions, in order to create impact and systemic change at scale.[80] The technology sector is more fragmented than most when it comes to trade associations and collaborative initiatives.

There have been important recent efforts, such as the Step Up Coalition for climate action, which includes 25 technology firms; the Cybersecurity Tech Accord, with more than 120 companies that have committed to protecting customers and users and helping them defend against malicious threats; and the Partnership on AI,[81] with more than 90 multistakeholder partners committed to advancing positive AI uptake. Initiatives are also emerging focused on tech and the Global Goals more broadly, such as 2030Vision,[82] which brings together 18-plus companies and organizations to look at how technology can help advance the Global Goals, and the Global Partnership for Sustainable Development Data, which includes hundreds of organizations, such as governments, companies and civil society groups.

These initiatives don't come close to the scale of collaboration that society needs. Public, private and multistakeholder collaboration, with active leadership from the technology industry, is urgently required in order to tackle the most systemic challenges in terms of opportunities. This applies to industry codes of conduct and frameworks on responsible technology; R&D on deploying technology to tackle the challenges underpinning the Global Goals; digital infrastructure and upskilling in underserved regions; and advocacy with governments to shape new standards, policies and regulations for tech policy, sector-specific policy, environment policy and structural policy.

Example recommendation:
Development of a multistakeholder platform, with the aim of developing and facilitating action-oriented and pragmatic partnerships to tackle challenges that prevent the scale-up of technology uptake and deployment for Global Goals, and driving the design, testing and scaling of innovative solutions.

4. Public policy: policies and regulation for the Fourth Industrial Revolution

There is a growing risk of politicizing new technologies, particularly as governments rush to win the race in powerful foundational technologies that are viewed as economic multipliers, such as AI, quantum and 5G. By contrast, the focus ought to be on balanced fit-for-purpose technology policy and regulation that both safeguards society and channels innovation towards positive economic, social and environmental outcomes. This is particularly pressing today as digital technology has progressed for several decades with remarkably little regulation, or even self-regulation. Successful policy and regulation have been found to be one of the vital missing pillars for making tech work for public goods. As an example, to support the deployment of blockchain the law needs to include provisions for trading tokens and digital assets.[83]

A successful enabling policy environment is one that is agile, coherent and cross-cutting across technology, sectoral, social and environmental domains. Each of these areas is discussed further in the box below on Policy principles for the Fourth Industrial Revolution.

Policy principles for the Fourth Industrial Revolution

Assertive but agile governance and policy

Currently, regulators in many jurisdictions have been playing an active role in monitoring developments and reacting as and when they see potential harm. This passive approach of waiting for an issue or risk to mature, however, leaves society exposed with substantial negative societal and economic impacts already taking place (e.g. digital identity theft, ransomware attacks, deep fakes, the rise of weaponized AI propaganda and misuse of facial recognition, to name but a few).

Given the nascency of industry applications of Fourth Industrial Revolution technologies and the speed of their evolution, governments and regulators could benefit from an agile and incremental approach, much as the tech sector innovates itself.[84] Step-by-step rules, responding to change rather than following a plan, and learning from experience, can help governments better keep pace with technology.[85] Input can also be sought on areas where societal and environmental implications are particularly present and pervasive to help prioritize where regulation is most critical.

An example of recent high-impact, technology-related policy leadership includes the EU's GDPR privacy protections under the Directive Right to Report Act, which has driven the technology industry to shift practices on personal data management.[86] Engagement with technologists and industry to establish a common voice on what's needed to help technology positively and meaningfully contribute to the Global Goals will also be vital – technologists need to sit down with governments and competitors to find common ground.

Norms, rules and coherence across borders

Fourth Industrial Revolution technology-relevant regulation today is predominantly on a jurisdiction-by-jurisdiction basis and firms operating platforms can, with relative ease, move their offices, important officers and/or primary servers to different jurisdictions. Policy differences across jurisdictions, including, at worst, conflicting requirements, are challenging given the distributed and transboundary nature of many Fourth Industrial Revolution technologies.

Building a more coherent international solution to Fourth Industrial Revolution governance, or even a more globally coordinated one – particularly for AI, blockchain, IoT and 5G – is critical to managing the risks to society and the environment. Governments will ultimately need to act together, which will require new international rules and norms as guardrails of borderless technologies, in particular to protect against unintended consequences of technology hindering the achievement of the Global Goals. Holding countries and companies accountable for non-compliance when negative impacts do occur will also be important.

Multilateral examples through the G20 and Financial Stability Board exist that could serve as a blueprint (e.g. the Task Force on Climate-Related Financial Disclosures (TCFD) climate risks framework, and the Financial Stability Board (FSB) crypto-assets risk framework).[87] However, not all jurisdictions may choose to implement the recommendations. Other examples include the US-EU Privacy Shield, the CLOUD Act's authorization for international agreements[88] and the long-term vision for a Digital Geneva Convention.[89]

Integrate the Fourth Industrial Revolution across sectoral, environmental and social policy

Country leaders are looking for solutions to their most pressing development priorities and need to do more to harness the power of fast-advancing technologies to achieve these goals. The Fourth Industrial Revolution affects every sector of the economy, and thus policy-making must extend well beyond technology policy. The implications of the Fourth Industrial Revolution on policy-making, be they national and sectoral policies and plans, labour market reforms or environmental and social policy-making, is critical.

In climate change, for example, where innovation and new technologies will be critical to making a net zero carbon transition possible, many Fourth Industrial Revolution-related decarbonization technologies can reach critical lift-off point, scale and replace incumbent solutions only if supported with clear environmental policies including carbon pricing, tax incentives, standards and subsidy reforms. Examples of enabling technology-specific policy that could play an important role in accelerating cleaner norms include standards for the energy efficiency of blockchain protocols, cloud servers and 5G networks, requiring electrification of all autonomous vehicles, mandatory environmental, social and governance (ESG) disclosure and environmental standards for digital assets procurement.

5. Finance mechanisms: stimulating the Fourth Industrial Revolution for good market solutions

Finance mechanisms, including blended finance or wider public finance mechanisms, can be a positive critical force to stimulate new market solutions. They are particularly critical to enable scaling of Fourth Industrial Revolution solutions where market failures exist, there is a challenging investment climate or the benefits are largely public goods. More broadly, by staying on top of the latest technology trends, governments, public finance institutions, companies and investors can back and scale new technology solutions that help countries leapfrog traditional systems. Doing this will enable collaboration between policy-makers, technologists, industry and finance to understand the future of technologies and the future of sectors in a world transformed by the Fourth Industrial Revolution. This can be done through three main channels:

1. **Innovation finance:** includes blended-finance support for early-stage commercialization and scaling of new technology solutions through government-backed innovation incubators, accelerators, funds and prizes; price-support mechanisms; and targeted patient and/or concessional capital to enable scaling of technological solutions for the public (social and environmental) good.

2. **Public procurement:** governments can play an important role in creating demand signals in relation to responsible technology through their own digital/technology procurement policies, from requiring technology suppliers to adopt established targets (e.g. in the "green" space – Science Based Targets, RE100, EP100 or EV100) and sustainability standards (ISO 14001), through to adopting wider responsible technology procurement protocols, including integrating ESG assessment and ethics guidelines, and applying tools and principles (e.g. UN Global Pulse's Risks, Harms and Benefits Assessment Tool).[90]

3. **Infrastructure investment:** includes Fourth Industrial Revolution-appropriate infrastructure investment decisions – for example, backing wireless over fibre optics or backing distributed renewables over traditional transmission and distribution power grids. And broader investments in electricity access, smart water and energy grids, earth observation and smart and connected urban areas. Blended finance, including innovative finance mechanisms such as price-support mechanisms, may well be needed to unlock the breadth and depth of infrastructure investment required.

Example recommendation:
Harness accelerator platform(s) to surface, support and connect innovators, investors, domain experts and strategic partners to help scale tech for Global Goals projects and ventures, both within and across markets. Examples to harness include the Forum's Uplink platform, and the SCALE 360 Circular Economy Innovation Accelerator, in addition to industry-led accelerators (e.g. TechStars Sustainability Accelerator, Microsoft's AI for Earth Accelerator, the XPrize community).

6. Breakthrough innovation: shaping an innovation agenda to tackle the most pressing social and environmental challenges

With capital and leadership committed, a clear R&D agenda needs to be set out where breakthrough innovation is central to tackle the priority, and toughest, challenges underlying the achievement of the Global Goals. These often require multi-country, multi-actor collaborations and partnerships. Take the issues of oceans or climate change: They are transboundary in nature; they require globally aligned policies and commitments from public and private actors to make progress; and their better management can benefit from global technology solutions.

Technologists looking to deploy their data, tools, talent and finance (commercial and philanthropic) towards societal grand challenges need to better understand the distinct problem domains – both as an investment framework to direct initial efforts and in order to build fit-for-purpose solutions. There is a need for agreement and prioritization of a global collaborative R&D agenda at all levels, from the R&D departments of technology companies, or industry, all the way up to government agencies. Breakthrough innovation on some transboundary public-good challenges, such as deep decarbonization technologies or oceans management, will require a multi-country and multistakeholder approach.

Example recommendation:
Establish a global "breakthrough tech for Global Goals" investment framework and encourage corporate and government R&D commitments to align around, and collaborate within, the framework.

7. Data and tools: new models for data collaboration for scaled Global Goal impact

While R&D and investment in specific applications is starting to progress, significant underlying barriers are preventing these from achieving scale, or moving beyond grant-based or goodwill-based pilots. One reason for this is the lack of business incentives or models that encourage the sharing of vast amounts of data, and the necessary investment to translate this data into usable insights that guide decision-making or action. Today, only one-fifth of government datasets are open.[91] Furthermore, many of the most powerful datasets relevant to the Global Goals are held privately, and in many cases in data monopolies held by a few large technology firms. Some of these private datasets will need to be accessed to realize the full potential of technology solutions for public goods.

New models of data collaboration and/or democratization of data for public benefit are required to overcome these fundamental roadblocks. While still in the early stages, models include those based on data cooperatives, data trusts and (blockchain-enabled) platform economics (where a network of actors are collectively compensated based upon their ability to deliver a measurable outcome or performance). To date, data collaboratives have been particularly successful in agriculture, including the engagement of community co-ops, and precision medicine domains. Data trusts in particular can not only build trust on privacy, security and data reliability, but also offer the means to (re)allocate the value of data products and services to individuals and local data producers and help address the fundamental issue of data ownership.[92]

Technology platforms and tools are needed to enable easier and more affordable data sharing, integration and management, including cutting-edge tools for managing, integrating and analysing diverse datasets in order to facilitate intelligent big data applications for societal and environmental benefits. This includes the creation of better data environments, including for machine-readable and structured data access, such as the Open Data Initiative – a recent private sector-led example of a technology platform and tools to help organizations federate data while maintaining their ownership and control of the data they share, and providing data formats suitable for sharing. Government initiatives for open public data, industry-government collaboration on data and code verification, or audits and policy frameworks (or agreements) or structures (e.g. data trusts and hybrid business models) to make strategic data available to specific users with clear safeguards and incentives will all be vital. IP and privacy issues will also be important; any solutions need to build an architecture to share data in privacy-protected ways compliant with the evolution of privacy laws. Finally, data quality and ethics will also be vital for open data platforms. Analytics developed from crowd-sourced raw data typically reflect the biases and prejudices inherent in broader society; practical arrangements will be needed to address and identify unfairness and discrimination in publicly sourced big data.

Case studies: Current efforts include:

- The Global Partnership for Sustainable Development Data, including the Data for Now initiative involving the United Nations and the World Bank Group, as well as Google and the Alibaba Group
- Open data initiative and California data collaboration that creates analytics for water shortages

Example recommendation:
A public-private game-changing effort to build big data and analytics capability on an "SDG mission control data collaborative". This global public goods data innovation could be a (close to) real-time open API digital dashboard of the Earth that would enable the monitoring, modelling and management of environmental and human systems at a scale and speed never before possible – from tackling illegal deforestation, water extraction, fishing and poaching to air pollution, natural disaster response and smart agriculture. This will require collaboration and coordination among entrepreneurs, industry, government and the non-profit sector, and incentives for all prime actors involved.

Example recommendation:
A database that provides investment advice to investors and developers alike: e.g. creating a municipal bond readiness scorecard/best practices of tax incentives to encourage certain technologies.

8. Skills: upskilling, reskilling, interdisciplinary talent and collaboration

The new challenges presented by Fourth Industrial Revolution technologies also require more active collaboration across multiple disciplines and stakeholder groups. Within companies, part of the answer requires that tech companies hire and/or work in partnership with broader talent across disciplines. Understanding is needed about real-world scenarios, the environment and sustainability, regulatory affairs and risk management, as well as public and government technology expectations, including ethics and human rights. Likewise, industry and broader private and public organizations require digital upskilling and data science talent to maximize value from the Fourth Industrial Revolution. Finally, education is critical to ensure vocational school and university graduates are ready to enter the job market with a view to being relevant in sectors in their local economies reshaped by the Fourth Industrial Revolution. At a more granular level, partnerships between academia, governments and the private sector could support the integration of environmental, societal and governance themes into data and computer science degrees, and vice versa (e.g. environmental and social science degrees integrating technology skills).

Case study: The Coalition for Digital Intelligence

The Coalition for Digital Intelligence is a multistakeholder community that will coordinate the implementation of the digital intelligence framework across both the technology and education sectors and could work to set general principles relating to digital basics, ethics and technology requirements.

Chapter 5: A call to action

Different stakeholder groups will have specific, but related, roles to play within the collective effort to speed up innovation, minimize risks and maximize the potential of technological solutions to pressing social and environmental challenges. As outlined in Chapter 4, the role, and ambition, of leaders – from companies and governments in particular – will be critical to help chart and manage the course of technology's broad societal and environmental impact.

Below, we set out the underpinnings of what a "call to action" could look like for two fundamental leadership groups (Table 4):

1. Government leaders (national, subnational and regional)

2. Tech sector executives

This call to action provides an organizing framework (or "blueprint") for coordinating, mobilizing and tracking commitments, and action, around a collective mission to accelerate and realize technology's potential to tackle the Global Goals. It can be viewed as a set of priority actions (or principles, in some cases) organized by vital pathways that can drive change (e.g. operations, R&D, policy). It also helps different stakeholders recognize the respective and complementary roles that each needs to play to change business as usual.

While focused on two priority stakeholder groups, the framing for technology executives is largely transferable to wider industry executives and investors. Likewise, wider stakeholder groups such as start-up entrepreneurs, international organization and NGO leaders or research leaders can also focus on specific action areas of priority relevance.

Mobilizing a leadership coalition to commit to a call to action, such as that outlined in Table 4 for tech and government leaders, is critical to moving markets at scale to accelerate "technology for society" outcomes. Cohesive ambition and action are needed, from committing to the implementation of strong ethical frameworks to driving fit-for-purpose policy and regulation, upskilling and reskilling, financing, data commons, directed R&D and even driving labour market reforms. It is necessary to move quickly beyond celebrating a smattering of "for good" use cases to leadership ambition in investing money, time and expertise and fully embracing this agenda.

Table 4: Action areas for leaders

Government leaders	
Tech policy – Develop responsible tech codes and standards (e.g. algorithmic accounting for AI) – Develop data protocols and protocols for appropriate delimitation of private data use around public-good outcomes – Support data security and identity enforcement	**Innovation finance** – Provide commercialization support for early-stage social and environmental entrepreneurship (e.g. incubators, accelerators, prizes) – Have price support mechanisms for tech for SDGs
Public procurement – Adopt established sustainability targets and standards (e.g. RE100, SBT, EV100) – Adopt responsible technology protocols within procurement policy – Ensure environmental standards for digital assets procurement	**Sectoral and environmental policy** – Integrate 4IR impacts into sectoral development plans and policies – Ensure robust carbon-pricing mechanisms and phase-out of carbon-intensive power generation – Introduce subsidy reforms – Ensure legislation and legal enforcement of environmental standards – Have mandatory ESG disclosure
Infrastructure investment – Ensure 4IR-enabled infrastructure investment (connectivity, EV charging networks, satellites, cloud infrastructure)	**Structural policy** – Reinforce social safety nets (incl. for AI economy) – Introduce next-generation labour market reform – Have policies to reskill and upskill workforce – Ensure education investment that deploys 4IR for impact
R&D investment – Support open-data initiatives focused on public good outcomes – Ensure basic and applied R&D finance focused on the intersection of tech and societal/environmental impact	

Tech executives	
Operations – Adopt responsible technology guidelines – Embed SDGs as a core operating principle – Set targets for sustainability in line with science and internationally agreed goals, and create incentives for implementation – Embed SDG performance into risk and compliance processes	**Finance** – Use pricing models (e.g. carbon price) as financial incentives for SDG performance – Establish investment fund for SDG outcomes and explore the use of corporate venture capital (CVC), treasury funds and blended purchasing power parity (PPP) models – Harness technology tools to enable sustainable and inclusive finance
R&D – Innovate new solutions through corporate research that is focused on big societal challenges – Establish R&D partnerships with multi stakeholders to tackle public goods challenges	**Skills and infrastructure** – Develop tech platforms for data sharing, integration and analytics – Set targets on upskilling in underserved communities and regions – Provide skills support to policy-makers on technology developments – Collaborate with educators
Policy – Promote purposeful policy advocacy at local, national and international levels, to create enabling regulations to achieve SDGs – Collaborate with peers, across sectors, and with business associations to coordinate advocacy – Ensure lobbying in line with SDG outcomes	**Governance and coordination** – Set board-level accountability for SDGs, including risk compliance – Have SDGs integrated into enterprise risk management (ERM) process, where appropriate – Introduce cross-company governance models
Philanthropy/pro bono – Support partnerships with non-profit organizations and academia to deploy technology for public-good challenges (e.g. grants and tools) – Democratize data, algorithms, APIs for delivering public good, and set targets and metrics around uptake	**Products and services** – Develop products and services to accelerate customers' ability to deliver SDG outcomes

Chapter 6: Conclusion

With only a decade left to meet the Global Goals, business as usual is not an option. We may still be in the early days of the Fourth Industrial Revolution, but we stand at a critical juncture to make decisions and put in place a policy and governance architecture to enable the digital age to deliver its full potential for humankind, across all countries of the world in the 2020s and beyond. The positive scenario of a technology-enabled sustainable future for all will not emerge unguided. Purposeful and decisive action, collaboration and coordination by organizations, investors and governments alike will be critical.

As the multitude of applications set out in Chapter 2 highlights, the opportunity for Fourth Industrial Revolution-enabled innovation to benefit humankind and our environment is real and substantial. The reality is that many of today's applications are nascent, sub-scale and cluster in areas with the clearest commercial market gains rather than for the public good. They also often depend on a wider supportive enabling environment, and technology infrastructure, to outcompete incumbent solutions. In some cases, we see that even highly feasible and technically scalable technology solutions are stuck at the concept or demonstration stages, particularly where they lack a clear short-term commercial business case. A new enabling environment is urgently needed, one that rewards and accelerates innovation that brings broader environmental and social value to the fore.

For technology to make the Global Goals a reality, we also have to manage the downsides of today's tech revolution. Emerging technologies are already creating an immensely uneven economic impact, a new landscape of warfare in cyberspace, new threats to democracy and a polarization of communities through big data and AI-informed propaganda, an erosion of privacy and an emerging capability for unprecedented surveillance of citizens. As the power, scale and impact of new technologies continues to accelerate, the hands-off approach to managing the impact of technology that we have – by and large – had to date risks potentially catastrophic consequences for society. Getting this right means managing risks and unintended consequences with foresight and decisiveness.

Purposeful innovation and deployment of new technology is a responsibility shared by all stakeholders – from the tech community (entrepreneurs and big tech alike) and industry sectors, through to governments and regulators, financiers and civil society organizations. The creation of a new "responsible technology" platform, enabling a broader ecosystem that focuses on harnessing technology to tackle the Global Goals, would be a valuable and much-needed next step. It could support the development of effective coalitions of the willing, and a leadership "call to action" in terms of breakthrough R&D investment priorities, policy advocacy, responsible technology codes of conduct, data and tools sharing and co-development of upskilling and infrastructure readiness efforts.

Annex

Annex 1: Global Goal definitions

1 NO POVERTY	Poverty alleviation and social protection
2 ZERO HUNGER	Access to food, improved nutrition and food-production security
3 GOOD HEALTH AND WELL-BEING	Advancing global health for all ages, and healthcare services
4 QUALITY EDUCATION	Inclusive access to education, quality of education and learning facilities
5 GENDER EQUALITY	Facilitating gender equality, protecting and empowering women and girls
6 CLEAN WATER AND SANITATION	Access to and sustainable management of water, and water sanitation
7 AFFORDABLE AND CLEAN ENERGY	Adopting sustainable energy, and energy-system optimization
8 DECENT WORK AND ECONOMIC GROWTH	Sustained and inclusive job creation and productivity, and improving workers' rights
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Building inclusive, resilient and sustainable infrastructure and industry
10 REDUCED INEQUALITIES	Facilitating equality and international collaboration
11 SUSTAINABLE CITIES AND COMMUNITIES	Building smart, inclusive, safe and resilient urban systems
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Supply-chain optimization and sustainable consumption patterns
13 CLIMATE ACTION	Combating climate change and its impacts
14 LIFE BELOW WATER	Conserving and managing the use of marine habitats and resources
15 LIFE ON LAND	Protecting and restoring terrestrial ecosystems
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Promoting peaceful society, building effective institutions
17 PARTNERSHIPS FOR THE GOALS	Building sustainable global partnerships

Annex 2: The core Fourth Industrial Revolution technologies considered in this report

Artificial intelligence

Software algorithms capable of performing tasks that normally require human intelligence, e.g. visual perception, speech recognition and decision-making

Blockchain

Distributed electronic ledger that uses software algorithms to record and confirm transactions with reliability and anonymity

Internet of things

Network of objects embedded with sensors, software, network connectivity and computer capability that can collect and exchange data over the internet and enable smart solutions

Big data

Extremely large datasets that may be analysed computationally to reveal patterns, trends and associations

Advanced materials

Materials with significantly improved functionality, including lighter weight, stronger, more conductive materials, e.g. nanomaterials and high-energy density batteries

Robotics

Electro-mechanical machines or virtual agents that automate, augment or assist human activities, autonomously or according to set instructions

Augmented/virtual reality

Computer-generated simulation of a three-dimensional image overlaid on the physical world (AR) or a complete environment (VR)

3D printing

Additive manufacturing techniques used to create three-dimensional objects based on “printing” successive layers of materials

Drones

Enabled by robotics, vehicles that can operate and navigate with little or no human control. Drones fly or move without a pilot and can also operate autonomously

5G

Latest iteration of cellular network providing significantly faster speeds and bandwidth and shorter delays, as well as improved battery life and portability

Synthetic biology

Interdisciplinary branch of biology applying engineering principles to biological systems

Annex 3: Methodology

Overview of approach
The methodology used in this analysis moves beyond identification of discrete technologies and is designed to develop a holistic snapshot of the extent to which combinations of technologies are (or are not) driving progress towards the Global Goals.

Step 1: Problem analysis
This methodology is problem-first rather than technology-driven, focusing first on the large problems that need to be solved and then looking at the technology applications that can help solve these problems and create impact. Our research and analysis, through desk-based research and interviews with a range of stakeholders, identified the important areas in which progress is slow.

Step 2: Global Goal-specific technology applications
Our analysis identified over 300 specific technology applications that have the potential to help progress towards achieving the Global Goal. From these applications, top technology applications for each Global Goal were identified, based on the following KPIs:

- Feasibility proven (i.e. the application is being deployed and creating impact today)
- Transformational impact (i.e. the solution directly addresses the priority challenge areas underlying the goal(s) and could disrupt current approaches)
- Adoption potential (i.e. the potential population size is large)
- Technology centrality (i.e. Fourth Industrial Revolution technology is a vital cog in the solution)
- Realizable enabling environment (i.e. policy and governance requirements can be identified and supported)

These top technology applications were identified as having the potential to significantly help progress towards the Global Goals.

Step 3: Innovation combinations
To help us identify the cross-cutting solutions that can be used to drive progress across one or more Global Goals, our analysis focuses on "innovation combinations".

Examples of these innovation combinations:

AI + sensors + big data + drones = **precision monitoring**

Sensors + robotics + AI + 5G = **autonomous vehicles**

This data lens was used because most innovations in the era of the Fourth Industrial Revolution are combinations of existing and new technology – combining not just fundamental technologies but entire fields of practice. We identified cross-cutting Innovation Combinations and from this analysis we were able to analyse which innovation combinations were the most common across all 17 Global Goals based on Global Goal technology application occurrences, which core technologies were vital to the innovation combinations identified and which innovation combinations were underdeveloped in certain sectors.

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