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Fourth Industrial Revolution for the Earth Series

Harnessing the Fourth Industrial Revolution for the Earth

In collaboration with PwC and Stanford Woods Institute for the Environment

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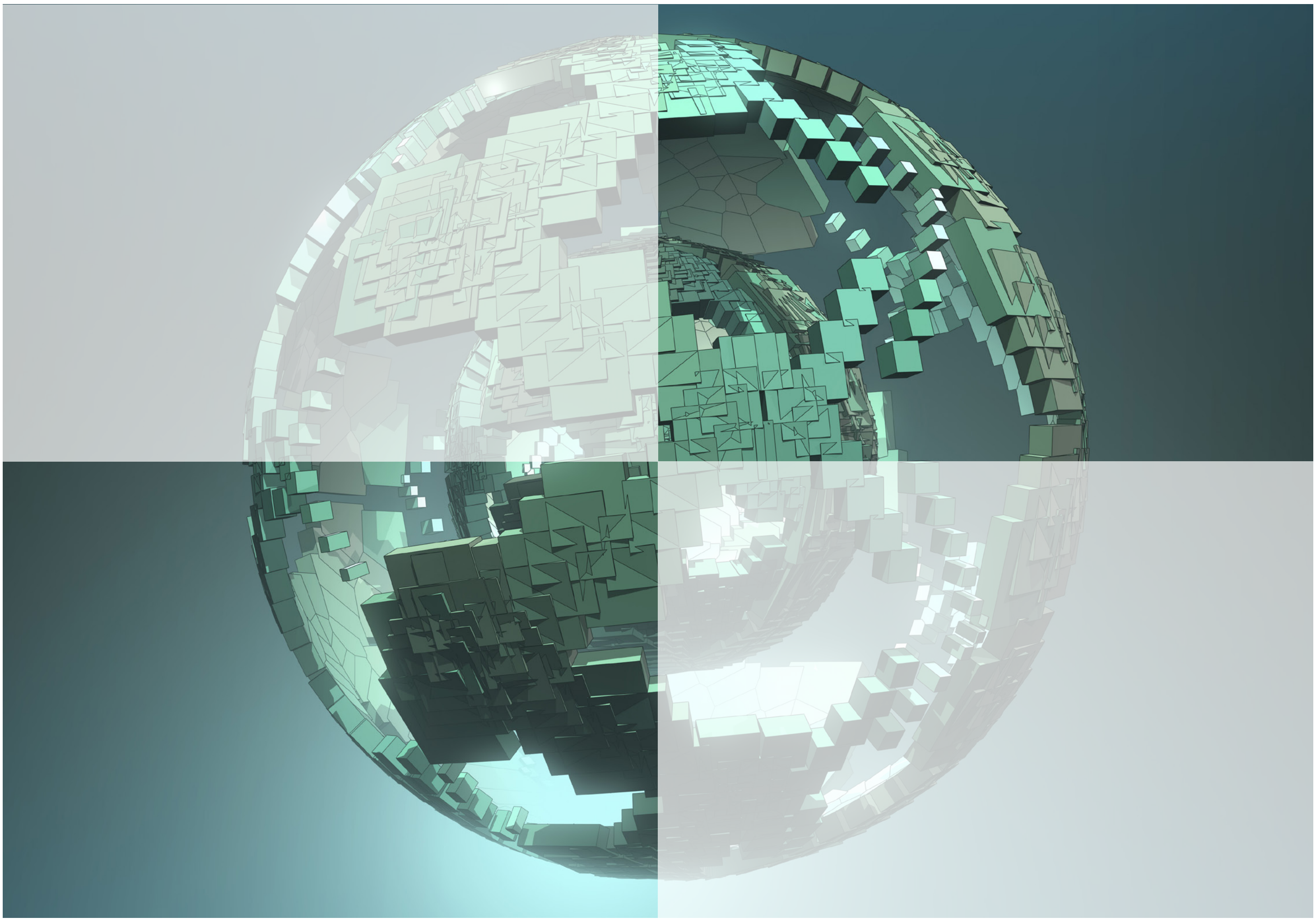

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About "The Fourth Industrial Revolution for the Earth" series

"The Fourth Industrial Revolution for the Earth" is a publication series highlighting opportunities to solve the world's most pressing environmental challenges by harnessing technological innovations supported by new and effective approaches to governance, financing and multi-stakeholder collaboration.

About the World Economic Forum

The World Economic Forum is an independent international organization committed to improving the state of the world by engaging business, political, academic and other leaders of society to shape global, regional and industry agendas.

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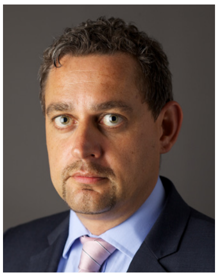
About 'The Fourth Industrial Revolution for the Earth' initiative

The World Economic Forum, with support from the MAVA Foundation, is providing its global platform for public-private cooperation and its Center for the Fourth Industrial Revolution in San Francisco to advance a major initiative – "The Fourth Industrial Revolution for the Earth".

This initiative will enable leading environment experts and technology innovators – drawn from across governments, international organizations, civil society, business, research, science and start-up communities – to form unique partnerships that identify, co-design and test policy innovations and technology applications for improving the world's environment and addressing natural resource security. The project will shape an agenda for how companies, governments and international institutions better understand and manage nature and the world's natural resources, making use of the latest science and technology for the benefit of all.

The initiative is in collaboration with PwC as official project adviser and Stanford University Woods Institute for the Environment as knowledge partner. It also works closely with leading issue experts and industry innovators from around the world, convened through the Forum's System Initiative and Global Future Council on Environment and Natural Resource Security.

Foreword



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Just one of today's standard tablet devices possesses the equivalent processing power of more than 5,000 desktop computers from the mid-1980s, the height of the NASA Space Shuttle programme. Storing 1GB of data in 1997 would have cost you more than $10,000 a year; today it costs you approximately $0.03. In 2001, the first human genome was sequenced. It took more than a decade and cost $2.7 billion. Today, a genome can be sequenced in a few hours and for less than a thousand dollars.[1] The first "App" appeared in 2008 when Apple founder, Steve Jobs, enabled outside developers to create applications for the iPhone. Today, not even a decade later, the app economy is worth $1.3 trillion, more than the total revenue for the global pharmaceutical market. WhatsApp, which was created in 2009, sends 55 billion messages a day.[2] News about everything from celebrity gossip to bad air quality now travels fast, and globally.

The Forum has termed this period of accelerating innovation in science and technology – the transformative change in data and technology capabilities combined with a merging of digital, physical and biological realms – and its impact on society as the Fourth Industrial Revolution. It is not only transforming social networks and scientific research, it is also radically reshaping the agenda for industries, governments and the international community.

In the same way that the Fourth Industrial Revolution is reshaping healthcare, mobility and education systems worldwide, it can reshape how the environmental community and its related institutions work. Scientists tell us we are facing more, and more urgent, global environmental challenges than ever before. This is despite all the international environmental agreements that have been established since the 1970s. Environmental professionals are aware they cannot be complacent. The policy-based and institutional approaches that worked 40 years ago are necessary, but no longer appear sufficient on their own to manage our growing environmental challenges. While their goals and targets are often sound, their ability to deliver the environmental outcomes required needs to be augmented. As a result, there is increasing interest, and great potential, in exploring how the science, data and technology innovations driving the Fourth Industrial Revolution could also be applied to improving environmental and natural resource management arrangements. This includes through technology and systems innovations that we might not yet even be able to imagine. If technology is starting to transform how we look after our health, surely it can also be harnessed to help transform how we look after our environment. For example, where is the wearable tech for measuring not only a person's heart rate, but also the quality of the air they breathe?

There is also a growing realization that these rapid advances in science and technology could also have unintended negative consequences on nature and people, which will need to be recognized, managed and avoided. With new technology comes the need for improved and more agile governance. For the Fourth Industrial Revolution to be the first fully "sustainable" industrial revolution, an effective enabling environment (approaches that help governments create smart safeguards, protocols, policies, and effective oversight and recourse mechanisms) needs to be put in place to avoid any unintended consequences and to ensure that society and nature benefit from this revolution. For example, if there were wearable sensors to measure the quality of the air people breathe, then who would control access to the data that was collected and how would it be used?

Governments, civil society and industry have important roles to play to help answer these questions, and develop principles and usage guidelines. A means of bringing stakeholders together to co-develop ways that make the most of these science and technology developments is needed. These will need to help us better understand and manage nature and our environment and avoid creating negative or unforeseen outcomes. This focus on developing policy principles must run alongside, and interact with, any acceleration programmes that promote the innovation and wider deployment of science and technology for environmental management.

This is the heart of the challenge. In practical terms, how can the environmental sector be helped to harness the science and technology revolution that is reshaping our wider economy and society so that current arrangements can be enhanced to better manage the environmental systems that sustain planet earth, given the increasing pressure nature faces from human activity? At the same time, how can policy principles and protocols be developed for use across the environmental sector so that risks from these new technologies to individuals, society or the environment itself are minimized and the opportunities maximized.

Humanity's current challenge

The great acceleration in human activity, particularly during the 20th century, has delivered exponential economic growth. Real output grew five-fold in the four centuries to 1900, before accelerating more than 20-fold in the 20th century.[3] The last 60 years, and the last 25 years in particular, have witnessed a further acceleration in human economic activity. Projections suggest that global economic growth will average approximately 3% per annum in coming decades. Although some economic commentators view this as a "slow growth world", this would still create a 20-fold increase in the human economic footprint by the end of the 21st century, while a 4% growth rate would yield a 50-fold increase.[4]

Previous economic growth has delivered impressive improvements in human welfare. For example, since 1990 the world has reduced the number of people living on less than $1.25 a day by one-half[5], and witnessed approximately 700 million more people move into the rapidly expanding global middle classes.[6] The world is on track to meet the (Organisation for Economic Co-operation and Development) OECD's 2010 forecast that the global middle class could double by 2020 and triple by 2030.[7]

Human success in reducing global poverty levels and expanding the middle class since the early 1990s has also spurred a wider economic power shift in the global economy.[8] Emerging economies now account for more than 40% of global GDP, doubling their share since 1990. Analysts forecast that the emerging middle-income economies and their rising middle classes could account for close to 60% of global GDP by 2050[9]; and more specifically, that almost one-half the world's GDP growth to 2025 will come from 440 cities in emerging markets – cities such as Kumasi (Ghana), Porto Alegre (Brazil) and Tianjin (China).[10]

Many argue that rapid urbanization has been the key to this economic success story. The speed and scale of the shift in human existence from rural to urban living for today's millennial generation is extraordinary.[11] In 1990, approximately 2 billion people lived in an urban environment; by 2014 this figure had almost doubled. By 2030, this figure is forecast to be 5 billion.[12] Today, there are 1,040 cities worldwide with more than 500,000 inhabitants, and 37 mega-cities with more than 10 million inhabitants.[13] The extraordinary difference in how most humans experience their existence today, compared to even 1990 is profound, especially when we consider that more than 40% of the world's population is under 25.[14]

A planet under stress

From an anthropocentric perspective, the last century (particularly the last few decades) of human existence has marked a very successful period for population and economic growth.[15] The recent past in particular, is a history of markets working, as technologies have driven progress and real commodity prices have fallen, despite a 20-fold increase in demand of some resources.[16] Based on the human experience to date, no one seems to seriously doubt the ingenuity of humans to meet the growth challenges being forecast to 2030 and beyond. A world of continued economic growth at levels of approximately 3% seems achievable, if not a little lacking in ambition.

Yet, from an Earth systems perspective, the human success story is not so positive.

Underpinning these extraordinary human advances has been the consistently steady state of the Earth's global environmental systems provided by the so called "Holocene equilibrium". Global patterns of temperature, precipitation, seasonality, and the overall health of our atmosphere, cryosphere, hydrosphere and biosphere, have remained predictable for much of the last 10,000 years. During this period, they have functioned within a "Goldilocks" zone – not too hot and not too cold – for humans.[17] This has provided a bio-physical environment conducive for humanity to flourish. In the success story to date of human economic history, the stability of global environmental systems has been taken for granted, as if they will never, and can never, be changed.[18]

Yet, the footprint of human impact on the Earth's global systems (particularly since the great acceleration of the last 40 years) has generated much scientific concern. Advances in recent decades in scientific monitoring and data collection, processing and modelling has enabled scientists to better assess and forecast the impact of human development on environmental systems.[19]

The findings are worrying. As a result of the historical, cumulative human footprint, many scientists' research suggests that the Earth could be entering a period of unprecedented environmental systems change.[20]

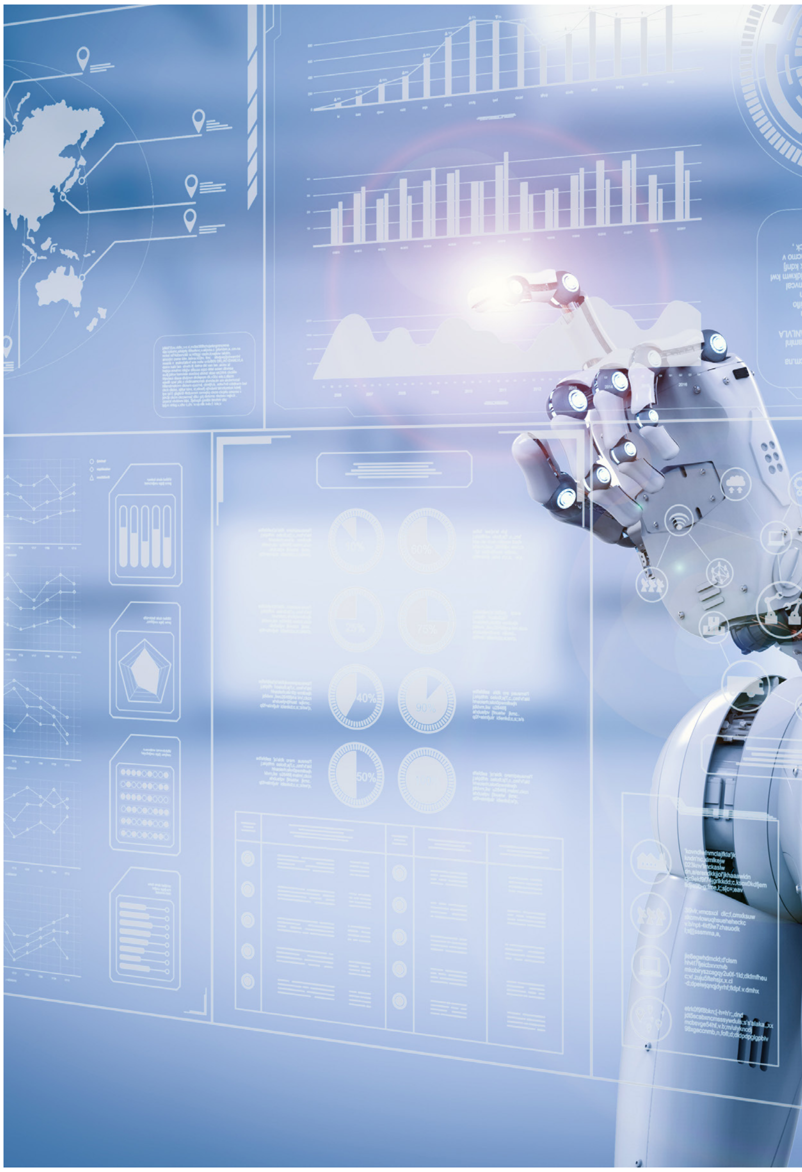
- **Greenhouse gases.** Today's greenhouse gas levels may not have been seen for at least 3 million years.[21]
- **Biodiversity.** The Earth is rapidly losing its biodiversity at "mass extinction" rates, such that 70% of its genetic biodiversity has become extinct.[22]
- **Deforestation.** Current deforestation rates in the Amazon Basin could lead to an 8% drop in regional rainfall by 2050, triggering a shift to a "savannah state", with wider consequences for the Earth's atmospheric circulatory systems.[23]
- **Oceans.** The chemistry of the oceans is changing faster than at any point in perhaps 300 million years because of the annual absorption of approximately 33% of anthropocentric greenhouse gas pollution.[24] The resulting acidification and rising temperatures of the ocean is having an unprecedented impact on corals and fish stocks.[25]
- **Ice fields.** Polar and glacial ice fields are retreating at an alarming rate with potentially calamitous knock-on effects for the wider water and climate systems.[26] The Arctic is now the fastest-warming region on the planet and the resultant warmer air and water at the North Pole is disturbing the predictability of the Gulf and the Jet streams,[27] which help to regulate the Earth's climatic circulatory system.
- **Nitrogen cycle.** We are suffering from arguably the largest and most rapid impact on the nitrogen cycle for some 2.5 billion years, as widespread nitrogen and phosphate pollution from poorly applied fertilizer has washed into seas. This has affected fish stocks and created so-called "dead zones" in 10% of the world's oceans.[28]
- **Water cycle.** The global water cycle is facing similarly severe impacts through over abstraction and uncontrolled pollution, with related analysis suggesting that the world may face a 40% shortfall in the freshwater needed to support the global economy by 2030.[29]

These are wide-ranging and serious impacts on the Earth's systems resulting from human activity. Scientists are also concerned that these impacts might even interconnect to trigger cascading "negative feedback loops", which could flip the Earth system into a wholly new state. This would likely be a period of environmental disequilibrium, something far from the Goldilocks conditions that the Holocene has provided for human activity to flourish over the last 10,000 years. The Forum's 2017 Global Risks Report reflects these concerns.[30]

Facing the future

Against this disturbing environmental backdrop, today's politicians and decision-makers are facing very real social and economic pressures. As the world rapidly urbanizes, more people than ever are demanding secure, safe and affordable supplies of food and energy, personal mobility and decent jobs.

The United Nations Food and Agriculture Organization (FAO) has estimated that global demand for food will increase 60% between 2006 and 2050.[31] This will require the world's farmers to produce more food in the next 40 years than they have done in the last 10,000 years.[32] The International Energy Agency (IEA) forecasts an increase in global energy consumption of approximately 30% by 2040[33], with a 71% increase in non-OECD economies.[34] This will lead to a 34% rise in global energy-related CO2 emissions by 2040 compared to 2012.[35] Meanwhile, the OECD's International Transport Forum forecasts that there will be approximately 2.5 billion cars on the road by 2050, up from just over 1 billion today.[36] Aircraft manufacturer, Boeing, estimates that global demand for commercial airliners will reach almost 40,000 in the next two decades,[37] which is double today's total fleet.



In search of a new approach

The standard international model used in the past 40 years to address our environmental problems has focused on the power of national governments to deliver outcomes, supported by international processes. For example, the use of international conventions or frameworks either for protection of areas on land and at sea, or to phase out dumping and pollution. These have been negotiated and agreed among the governments, while leeway has been given at the national level on how each nation might honour the particular framework. Typically, specialized public funds and (often time-bound) protocols and targets, with corresponding national voluntary plans, have augmented these global conventions. There have been some notable successes with this model, e.g. the Montreal Protocol for ozone depleting substances agreed in 1987, recently revised to also include HFCs.[38]

Arguably, however, and despite best efforts, in the aggregate the environmental indicators of planetary health have not improved. Things may be less bad than they would have been without these various international efforts since the 1970s, but the situation has still deteriorated, and potentially, there is worse to come.

It could be argued that these models for fixing global environmental challenges may have a few design weaknesses when considered in the context of the mid-21st century. To date, it has generally been officials in the international environmental community who have designed and negotiated international environmental conventions and agreements. They have attempted to reactively try to protect different parts of the global environment against the effects of economic activity (pollution, degradation etc).[39] As a result, they have tended towards the development of expert and technical protocols (e.g. tackling hazardous waste, mercury pollution and soil degradation) rather than presenting themselves as “platforms for action”. Such platforms could encourage a broader base of stakeholders (private-sector, city leaders, investors, civil society etc) to proactively try to transform those industrial or urban systems that are creating pressure on the environment in the first place. By effectively “ghettoizing” approaches for environmental management within the official environmental community, there has been limited engagement opportunity for a broader group of stakeholders to partner in problem solving. This model has arguably had the unintended consequence of limiting innovation.[40] This poses some difficult questions, especially as the scale and complexity of global environmental challenges seem to be getting worse and becoming more urgent to resolve.

Albert Einstein said: “The definition of insanity is doing the same thing over and over again and expecting different results.” History would suggest that there will be insufficient improvement in the global environment system if the international environmental community only promotes more of the same kinds of management models into the mid-21st century. In addition to current strategies, what *new* forces can also be harnessed to accelerate innovation and increase the scale of action under way? What *new* models can also be deployed to help fix environmental challenges? How can these innovations be put-to-work in ways that complement and strengthen existing international environmental processes, goals and targets to reinvigorate (rather than ignore or restart) the global environmental agenda as a curator and driver of innovation?[41]

The Fourth Industrial Revolution

The shift in economic power and acceleration in middle class growth, consumer demand and urbanization in recent decades has coincided with extraordinary progress in communications and technology. This has enabled societies to become more connected and have more data available to a degree impossible to conceive even just 25 years ago at the time of the first Earth Summit. Sir Tim Berners Lee created the first web server and browser in 1990 and email barely existed in 1992.[42] Now 46% of the world's population uses the internet and approximately 269 billion emails are sent daily.[43] In 2000, just 12% of the world's population had a cell phone subscription;[44] by 2015 it was 63%.[45] The rise of the smartphone means that mobile internet traffic is accelerating at more than 60% per year;[46] an astonishing growth rate when one considers exponential trends. To this end, the smartphone has become essential; in 2016 approximately 3.8 billion people had a smartphone subscription, a figure that is projected to rise to approximately 6 billion by 2021,[47] with 90% of the growth coming from emerging regions.[48] A total of 87% of US millennials say that the smartphone now never leaves their side and 44% use their camera or video function daily.[49]

As technologies like smartphones are also becoming increasingly powerful, common and connected, the merging of digital, physical and biological realms is accelerating. For example, wearable wellness technologies, which can help monitor vital health and fitness signs, connect the wearer with their doctor 24/7, and provide clouds of valuable public health data for officials to monitor, process and run predictive algorithms on, all at once.

The Forum terms this explosion in access to a ubiquitous and mobile internet, by smaller and more powerful sensors that are becoming ever cheaper, and characterized by artificial intelligence and machine learning as the Fourth Industrial Revolution. Its potential to radically transform the management of our environmental surroundings appears boundless. For example, what if wearable technologies could also monitor the quality of the air the wearer breathes, or the quality of the water they are drinking, as well as the rate of their heart?

Over and above the expansion of such personal data gathering and – when scaled up – new networks and movements that can leverage ever more powerful digital platforms for social connectivity and environmental information sharing, the internet of things (IoT) also offers great potential for innovation in environmental management. There are already approximately 8.3 billion connected industrial devices covering products from cars, homes, appliances and industrial equipment. Analysts suggest this will reach more than 20 billion by 2020.[50] When combined with rapid advances in data processing and technology innovation, IoT could help drive countless localized initiatives. These could include smart street lighting and energy efficient buildings,[51] or even real-time city-wide "urban dashboards" of interconnected environmental information across buildings, transport systems and industry enabling optimized energy, emissions and environmental footprint management.

The Fourth Industrial Revolution also encompasses specific clusters of transformative technologies such as artificial intelligence (AI), robotics, additive manufacturing (or 3D printing), neurotechnologies, drones and autonomous vehicles, biotechnologies, virtual and augmented reality, and blockchain, along with technologies and capabilities that haven't yet been created. All of these could offer profound implications for innovative approaches to managing environmental footprints. (A list of current Fourth Industrial Revolution technology clusters most applicable for the environment can be found in Annex I.)

The Fourth Industrial Revolution is, however, about more than just identifying technology game-changers. It also encapsulates the need for society to recognize and manage the "systems change" that these technologies create. For example, the arrival of the Spinning Jenny in 19th century Britain not only revolutionized cloth manufacturing, but also drove demand for child labour. Children were employed to climb underneath the machines to fix difficult-to-access parts when the loom broke. This prompted a revolution in child labour laws and child protection legislation and ultimately the right to childhood education, exemplifying a wider societal systems change prompted by technology.

The Fourth Industrial Revolution is also providing an opportunity – and a need – to pre-emptively rethink governance structures and to innovate to ensure they are updated and purpose-built for the 21st century, comprising the policies and protocols that societies feel their governments and the markets should have in place. These will include policies to minimize the risks and maximize the opportunities to society of the technology transformation. This is particularly important for society's poorest and weakest, who will require policies to support the transformation in jobs or to ensure access to information. It is also pertinent for protecting and managing the health of the environment, which is a public good upon which everyone depends. For example, if wearable technologies start to capture personal data on exposure to air and water quality levels, then questions will arise as to who should own this aggregate personal information, who should be able to access it and how might society best use it?

The challenge is to find the balance between exploring the innovations that technology offers for improving the environment, while developing ways and means to ensure that risks are minimized and opportunities are maximized. The next section looks at these issues in greater depth.

A revolution for the environment

The potential to harness the Fourth Industrial Revolution to help transform how humanity manages its environmental footprint and, more fundamentally, to re-imagine how human and economic systems might interact with the natural world (e.g. through cities, transport and energy networks, production and consumption systems, financial markets and agricultural and industrial value chains) appears potentially boundless. In exploring this transformation, however, the debate needs to focus not just on technological applications, but also on reshaping mindsets, incentives, policies and institutions. This will be critical to building inclusive, sustainable, resilient and ethical systems. The following illustrations offer a glimpse of the breakthrough transformations that are becoming available.

In transport

Advanced materials are close to enabling breakthroughs in battery design and production, which could create inexpensive, quick-charging and energy dense batteries that would outperform internal combustion engines. The growing market for electric cars is forecast to displace oil demand by approximately 2 million barrels per day by 2025, rising to 16 million by 2040. An oversupply of 2 million barrels per day was attributed as triggering the major oil industry downturn experienced during the last three years, which has been described as the biggest in a generation.[52] Meanwhile, commentators have described moves to produce autonomous vehicles as the new arms race.[53] There is a risk that technology, data, expertise and decision-making will become concentrated in the hands of a relatively small set of market leaders. Technology companies have become direct competitors of traditional automotive companies, and it's the mobility services software, not the hardware, where competition is most fierce. This creates a new governance challenge, which spans multiple industry sectors and technology sets and requires cooperation between the public and private sectors.

Through connected products and services

The rapidly growing IoT network and capabilities hold great promise. In China, the digital car-ride company, Didi, receives more than 20 million orders daily, twice the number of rides of all other markets in the world. Didi operates in 400 cities across China, engaging 17.5 million drivers, and car-pools approximately 2 million passengers daily. This pooling is taking approximately 1 million vehicles off the roads each day. In 2016, it is estimated that this avoided Greenhouse Gas (GHG) emissions of 1.4 million tonnes of CO2, along with providing the associated benefits of reduced air and Hydrofluorocarbon (HFC) pollution from vehicle air conditioners. Today, there are 200,000 electric cars in Didi's fleet and this is set to rise to 1 million within the decade.[54] New public-private platforms are under development to help cities in China share information locally and globally about: how to enable car sharing to reduce pollution; how to redesign city streets to enable these innovations; and how to work with the car and truck industry to accelerate production of electric vehicles designed for passenger sharing/optimal logistics delivery and ready for autonomous driving.

In product traceability

Geospatial data monitoring platforms such as the Global Forest Watch, Global Fishing Watch and Eyes on the Sea utilize advanced sensors and satellite imagery, combined with big data analytics, to enable anyone with a smartphone to track and monitor activity within important environmental systems. These are just the first releases – future iterations could leverage AI, such as machine learning to forecast where illegal fishing or logging is likely to occur. When complemented by other Fourth Industrial Revolution innovations, such as the ability to rapidly undertake DNA sequencing of seafood products and bilge water from ships, there is the potential to create greater transparency and accountability from "ocean to plate", giving consumers and regulators confidence in the sustainability and legality of products.

These platforms will generate, but also rely on, a wealth of data gathered from multiple sources, potentially including satellites, ships, ocean drones and DNA sequencing. As part of this project, dialogue is already under way to explore how alliances among data providers and data processors can help them to better apply their collective efforts to the challenge of environmental management.

On the blockchain

The potential of blockchain provides another good example of what might be possible in terms of a wholesale transformation in our approach to global environmental commons management. Blockchain is a distributed ledger, utilizing a secure protocol where a network of computers can collectively verify a transaction before it can be recorded and approved. It enables people who do not know each

other to collaborate without having to go through a neutral central authority. It offers its users a shared, programmable, secure and trusted ledger, which no single user controls but which can be inspected by everyone. Blockchain was the enabling technology for bitcoin. However, its potential applicability for widespread use in other areas is just starting to be realized. The Government of Sweden is already exploring the potential of blockchain to help with land rights management,[55] while entrepreneurs are exploring similar applications in Ghana, Georgia and Honduras.

Could a distributed ledger like blockchain play a role in managing global greenhouse gas emissions? By 2030, when most of the world's households will have a least one 3G cell phone and the global emissions trajectory is expected to have stabilized, perhaps there could be a worldwide blockchain for mobile carbon trading. The technology would ensure a transparent system where algorithms were used to assign every person on the planet a science-based carbon budget, which people could then trade. Such a system could potentially spur the next generation of a global climate framework, removing the political and institutional challenges that governments and international regimes, frameworks and systems currently face.[56] It would also facilitate market-driven financial flows to people in poorer nations who typically produce fewer greenhouse emissions. Perhaps a blockchain-style distributed ledger could also be used for managing water allocations and deforestation.

In monitoring greenhouse gas emissions

Rapid advances in satellites, drones and advanced sensors – augmented by smart algorithms or AI technology – could provide a real-time flow of data on GHG emissions, which would then be relayed across the cloud to be tracked by anyone from government officials to schoolchildren. This would greatly improve the transparency of Monitoring, Reporting and Verification (MRV) data, which is crucial for the accountability and efficacy of global climate agreements. The political implications could be transformative, as could be similar real-time satellite and drone monitoring of industrial GHG emissions for investors, insurers and regulators. No longer would disclosure regimes rely on companies choosing when and how to report. Instead, the information would be available, possibly in the blockchain, for all to see and to act upon.

In understanding the value of our biodiverse inheritance

An unprecedented acceleration in science and technology innovation is now helping researchers to map, sequence and replicate biology on Earth in new ways. This uncharted period of analysis may change society's perception of nature from a commodity to be exploited to a unique endowment that contains wholly new levels of value for society in the future. For example, studies within the Amazon of the ant, *Eciton burchelli*, using computational chemistry and AI have identified that the species uses swarm intelligence to ensure their worker ant army (numbering in the hundreds of thousands) avoids traffic congestion. This is inspiring the development in AI algorithms of autonomous, shared and electric power transport systems.

The Earth Bio-Genome Project (EBP) aims to sequence all the plants, animals and single-celled organisms (the eukaryotic species) on Earth within 10 years, to help us unlock the vast potential of our biodiversity inheritance. The EBP will rely on innovative, multi-stakeholder collaborations drawing on the science, research and ethics community, governments and the private-sector. The EBP has the potential to help redraw several components of the Convention on Biodiversity by the COP in 2020, when new targets need to be agreed. The Amazon Third Way initiative is a project working in partnership with the Earth Bio-Genome project to map the DNA of the Amazon Basin (creating an "Amazon Bank of Codes") to help create a proof of concept for the wider EBG methodology. The Amazon Bank of Codes will be an open, global digital platform, which registers and maps the genetic sequences of Amazon biodiversity. It will also register biological and biomimetic IP assets on blockchain, providing a regulatory platform to help implement the fair sharing of benefits as intended by the 2017 Nagoya Protocol, which governs access to genetic resources.

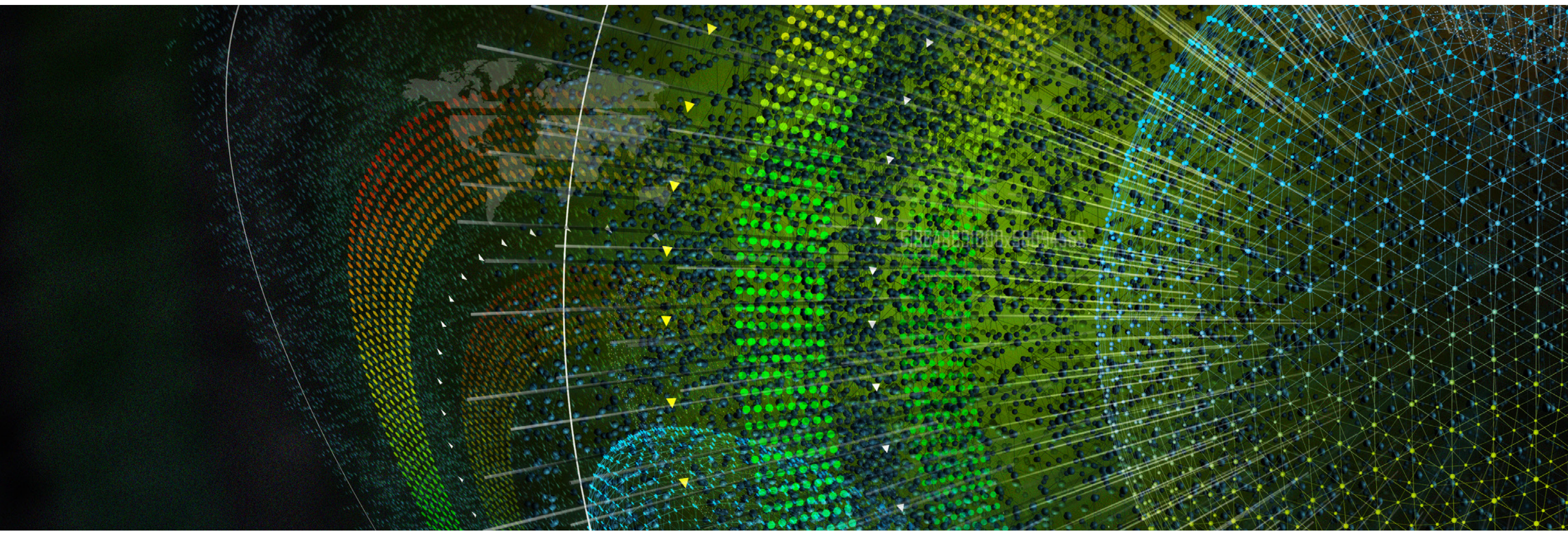
These are just a few examples of the ways Fourth Industrial Revolution innovations in science and technologies could be applied to transform current approaches to environmental issues. Much more work is needed to explore and refine the possibilities. Further help will also be required to scale those applications that are already available.

Risks as well as opportunities

For all the potential of the Fourth Industrial Revolution, it also poses many and various risks.

A widespread digital revolution in the global environment seems just around the corner[57] and data will be an increasingly prized asset, but there are important questions to be resolved about who owns and has access to which pieces of data. If environmental data becomes proprietary (either by design or default) this could limit access for those wishing to develop applications for the public good (whether for profit or not-for-profit). Disconnected platforms and competing networks of data provision may also emerge, each using their own data protocols and standards. To ensure data can be accessed and utilized effectively for innovative environmental applications, it will be important to ensure interoperability. Common protocols and standards may need to be created. New market and finance models may also be required, along with new or augmented roles for international environmental organizations. Could such organizations become the curators of global environmental information? If so, how will this work? How can they change their culture to attract the public- and private-technology talent they will need to keep abreast of the latest technology developments, remain cyber secure, and curate global platforms of environmental data? How will they avoid being seen as monopolies holding our earth system data for their own purposes, rather than being platforms for promoting widespread and open innovation? These big questions will need addressing.

Many of the Fourth Industrial Revolution innovations that hold great promise for disrupting how we manage the global environmental commons may also pose great risks, particularly if not implemented with the support of appropriate governance systems. For example, rich new streams of information about ocean conditions and fish stocks can help improve the sustainable management of ocean resources, in line with the Sustainable Development Goals (SDGs). This same data could also radically improve the transparency and traceability of legally fished seafood products, providing new tools in the fight against illegal fishing, which represents an annual theft of $23 billion.[58] However, if an international organization that hosted this data was hacked, these same data innovations could enable even more intensive illegal fishing by helping unregistered and unreported boats to find prime target stocks and escape enforcement. Similarly, tech-savvy poachers could access new sources of data on the location and habitats of protected species; on land, some poachers are already using geo-tagged photos posted on social media sites by tourists to locate endangered animals.[59]



Building the right 'enabling environment' is critical

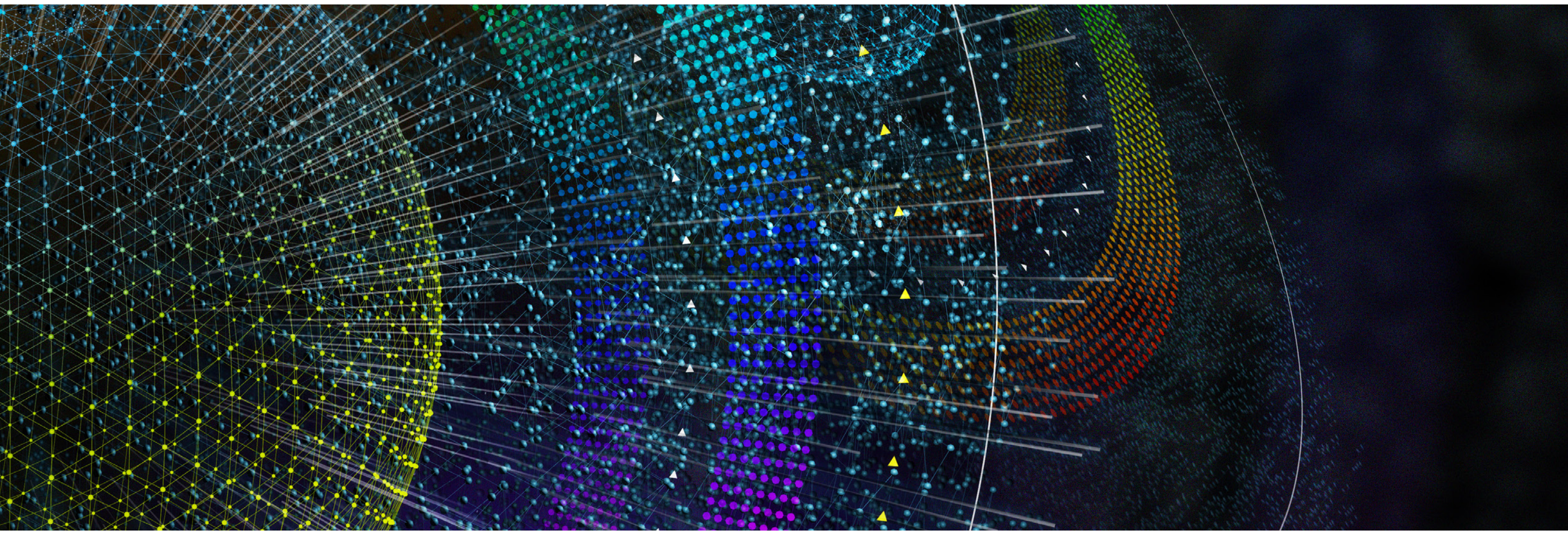
Realizing the opportunities available while also effectively managing potential risks will not happen automatically. Proactive, collaborative processes with policy-makers, scientists, civil society and technology champions will be required so that commonly agreed policies and protocols are developed and trialled concurrent to the acceleration and adoption of new technologies for environmental management and improvement.

The following kinds of collaborations will be particularly important:

- **Dialogues and partnerships that bring technology developers and providers together with environmental experts** to co-develop these innovations and to ensure they are developed for the public good, while minimizing risks of unintended environmental consequences.
- **Innovative investment platforms, financing structures, and business models** that can accelerate the scaling of promising environmental innovations, regardless of whether they have a clear commercial proposition or are less profitable "public good" applications.
- **Partnerships with governments and international institutions to enable the development of common and agile governance systems**, including the championing of common policy principles for managing new technologies (e.g. those recently developed for the G20), and the development of specific policy frameworks and protocols, transparency mechanisms, and equity related checks and balances for particular use case examples.

The speed of innovation in the Fourth Industrial Revolution means these partnerships and platforms to develop protocols and governance systems need to be developed early. This needs to take place in conjunction with the development of the technologies themselves, rather than as a reactive afterthought. Partnerships and platforms also need to remain agile, and able to adapt and change policies and protocols as nimbly as the technology itself evolves.

There is a unique opportunity to harness the Fourth Industrial Revolution, and the societal shifts it triggers, to help reimagine the models for how we manage our shared global environment and natural resources. If we get the design of both the technology applications and the "enabling environment" right, there is huge potential for a revolution in managing our environmental future. It will, however, require a significant effort in public-private and civil society collaboration, and it will redraw many of the current issue and institutional boundaries of who feels responsible for what, in today's global environment community. It will also require the environmental community to open up and engage many different actors into a multistakeholder agenda to help manage our global environmental commons. This may be challenging, but given the pressure the Earth's systems are under, the global community cannot afford not to try.



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About the Fourth Industrial Revolution for the Earth Initiative

The World Economic Forum is collaborating with PwC (as official project adviser) and the Stanford Woods Institute for the Environment on a major global initiative on the Fourth Industrial Revolution for the Earth. Working closely with leading issue experts and industry innovators convened through the World Economic Forum's Global Future Council on the Environment and Natural Resource Security, and with support from the MAVA Foundation, this initiative combines the platforms, networks and convening power of the Forum and its new Center for the Fourth Industrial Revolution in San Francisco. It also brings Stanford University's cutting edge research departments and connections with the Silicon Valley technology community together with the global insight and strategic analysis on business, investment and public-sector issues that PwC offers. Together with other interested stakeholders, this unique partnership is exploring how Fourth Industrial Revolution innovations could help drive a systems transformation across the environment and natural resource security agenda.

Annex I
List and description of Fourth Industrial Revolution technology clusters most relevant for environmental applications

Fourth Industrial Revolution technology clusters

The following descriptions[60] are provided as background and are not intended to be exhaustive.

- **3D Printing**. Additive manufacturing techniques used to create three-dimensional objects based on “printing” successive layers of materials.
- **Advanced Materials** (including nanomaterials). A set of nanotechnologies and other material science technologies, which can produce materials with significantly improved or completely new functionality, including lighter weight, stronger, more conductive materials, higher electrical storage (e.g. nanomaterials, biological materials or hybrids).
- **Artificial Intelligence**. Computer science learning algorithms capable of performing tasks that normally require human intelligence and beyond (e.g. visual perception, speech recognition and decision-making).
- **Robotics**. Electro-mechanical, biological and hybrid machines enabled by AI that automate, augment or assist human activities, autonomously or according to set instructions.
- **Drones & autonomous vehicles**. Enabled by robots, autonomous vehicles can operate and navigate with little or no human control. Drones fly or move in water without a pilot and can operate autonomously or be controlled remotely.
- **Biotechnologies**. Encompassing bioengineering, biomedical engineering, genomics, gene editing, and proteomics, biomimicry, and synthetic biology this technology set has applications in areas like energy, material, chemical, pharmaceutical, agricultural and medical industries.
- **Energy capture, storage, and transmission**. New energy technologies range from advanced battery technologies through to intelligent virtual grids, organic solar cells, spray-on solar, liquid biofuels for electricity generation and transport, and nuclear fusion.
- **Blockchain** (and distributed ledger). Distributed electronic ledger that uses cryptographic software algorithms to record and confirm immutable transactions and/or assets with reliability and anonymity. It has no central authority and allows for automated contracts that relate to those assets and transactions (smart contracts).
- **Geo-engineering**. Large-scale, deliberate interventions in the Earth’s natural systems to, for example, shift rainfall patterns, create artificial sunshine or alter biospheres.
- **Internet of things**. A network of advanced sensors and actuators in land, air, oceans and space embedded with software, network connectivity and computer capability, which can collect and exchange data over the internet and enable automated solutions to multiple problem sets.
- **Neurotechnologies**. Technologies that enable humans to influence consciousness and thought through decoding what they are thinking in fine levels of detail through new chemicals that influence brains for enhanced functionality and enable interaction with the world in new ways.
- **New computing technologies**. This includes technologies such as quantum computing, DNA-based solid state hard drives and the combining of Third Industrial Revolution technologies (e.g. big data, cloud) with the other technologies (e.g. IoT, advanced sensor platforms). Quantum computers make direct use of quantum-mechanical phenomena such as entanglement to perform large-scale computation of a particular class of currently impossible tasks by traditional computing approaches.
- **Advanced sensor platforms** (including satellites). Advanced fixed and mobile physical, chemical and biological sensors for direct and indirect (remote sensing) of myriad environmental, natural resource and biological asset variables from fixed locations or in autonomous or semi-autonomous vehicles in land, machines, air, oceans and space.
- **Virtual, augmented and mixed reality**. Computer-generated simulation of a three-dimensional space overlaid to the physical world (AR) or a complete environment (VR).

Annex II
The Fourth Industrial Revolution for the Earth initiative

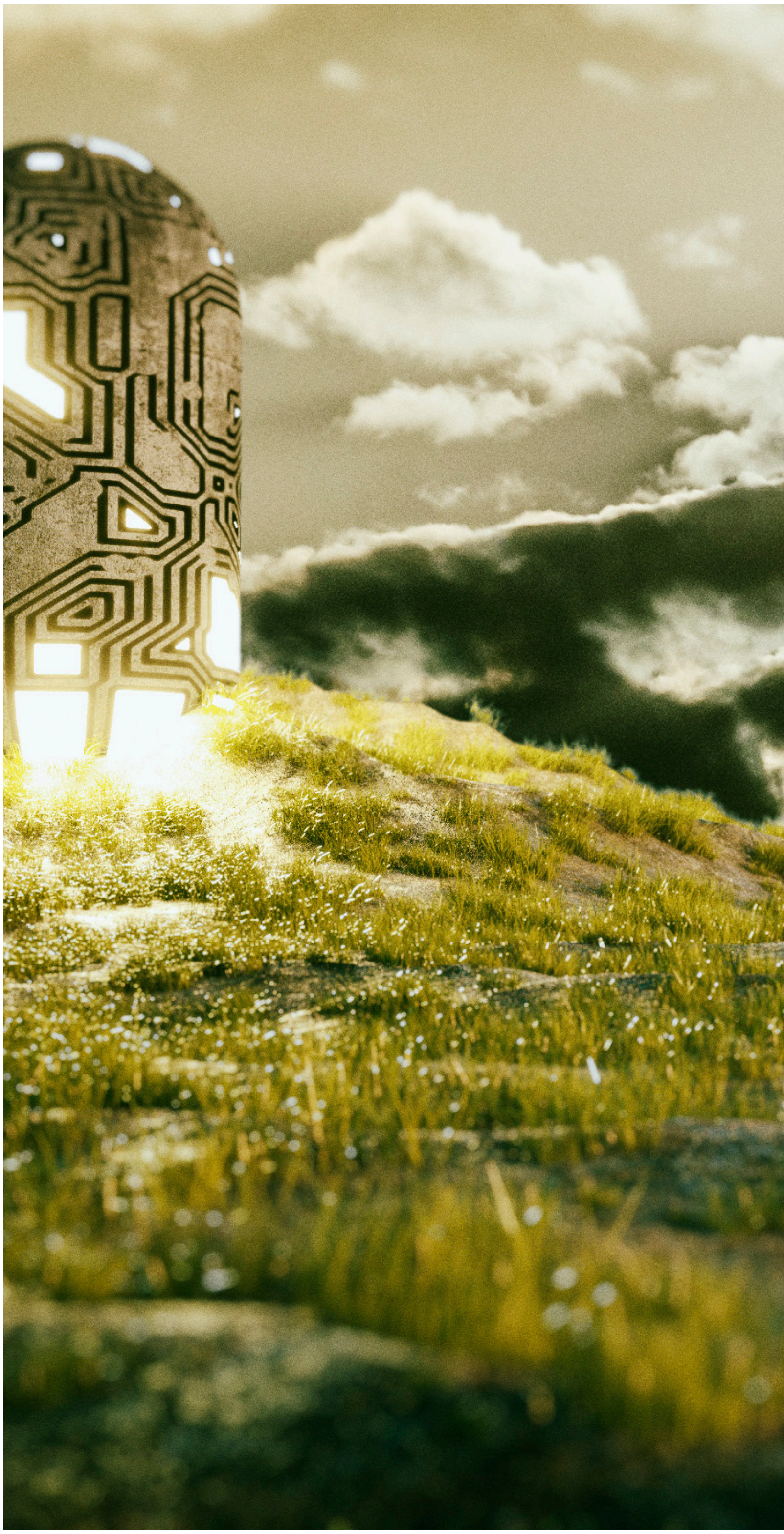
The Fourth Industrial Revolution for the Earth initiative is designed to raise awareness and accelerate progress across this agenda for the benefit of society. In the first phase of the project, specific environmental focus areas will be considered in depth, exploring in detail how to harness Fourth Industrial Revolution innovations to better manage the world's most pressing environmental challenges. Initial focus areas will include:

- Air pollution
- Biodiversity
- Cities
- Climate change and greenhouse gas monitoring
- Food systems
- Oceans
- Water resources and sanitation

Working from these thematic areas the Forum, supported by Stanford University and PwC (as project adviser), and advised by the members of the Global Future Councils on the Future of Environment and Natural Resource Security and specific Fourth Industrial Revolution clusters, will seek to leverage their various networks and platforms to:

- **Develop a set of insight papers,** taking a deep dive into the possibilities of the Fourth Industrial Revolution and each of these issues.
- **Build new networks of practitioners** and support them to co-design and innovate for action on the environment in each of these issue areas, leveraging the latest technologies and research that the Fourth Industrial Revolution offers.
- Design a **public-private accelerator for action**, enabling both government, foundational, research, organization and commercial funds to be pooled and deployed into scaling innovative Fourth Industrial Revolution solutions for the environment.
- Help government stakeholders to **develop and trial the requisite policy protocols** that will help Fourth Industrial Revolution solutions for the environment take hold and develop.

The Fourth Industrial Revolution for the Earth initiative will be driven jointly out of the World Economic Forum Center for the Fourth Industrial Revolution in San Francisco and other Forum offices in New York, Geneva and Beijing.



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