World Economic Forum

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Fourth Industrial Revolution for the Earth Series

Harnessing the Fourth Industrial Revolution for Life on Land

Towards an Inclusive Bio-Economy

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"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.

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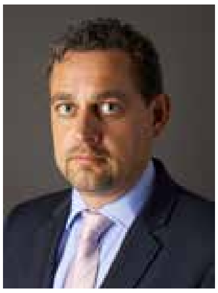
The Fourth Industrial Revolution and the Earth



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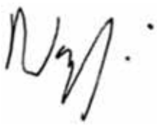


The stress on the earth's natural systems caused by human activity has considerably worsened in the 25 years since the 1992 Rio Earth Summit in Brazil.

As a result of the "great acceleration"[1] in human economic activity since the mid-20th century, research from many earth system scientists' suggests that life on land could be entering a period of unprecedented environmental systems change. For example:

- The earth is losing its biodiversity at mass extinction rates. One in five species on earth now faces extinction and scientists estimate that this incidence will rise to 50% by the end of the century unless urgent action is taken.[2]
- A record 29.7 million hectares of tree cover was lost in 2016 – an area about the size of New Zealand. Worryingly, this loss is about 51% higher than in 2015.[3]
- Today's greenhouse gas levels have not been seen for at least 3 million years, with carbon dioxide levels likely to remain above 400 parts per million. Record-breaking temperatures were recorded in 2014, 2015 and 2016, with 2017 set to break records too.[4]
- Water security experts at the International Water Management Institute (IWMI) fear that, within the next decade, up to 30% of food production may be at risk because of climate induced water stress. The IWMI also estimates that more than 70% of rivers in the world are now so abstracted that they hardly reach the sea.[5]
- Widespread nitrogen and phosphate pollution from poorly applied fertilizer has washed into seas over the past few decades, affecting fish stocks and creating, among other effects, oxygen starved "dead zones" in over 400 locations around the world.[6]

These are wide-ranging and serious impacts on the earth's land systems resulting from human activity. Scientists are concerned that they might even interconnect to trigger cascading "negative feedback loops". These could flip the earth system into a wholly new state, characterized by a period of environmental disequilibrium, something far from the "Goldilocks" conditions (not too hot and not too cold) that the Holocene period has provided for human activity to flourish over the last 10,000 years.

Yet, at the same time as this great acceleration in human activity has put unprecedented pressure on our earth systems, so too has an incredible transformation taken place in our science and technology capabilities. It is now possible to understand and model complex systems at unprecedented speed and scale.

Just one of today's standard tablet devices possesses the equivalent processing power of over 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 more than $10,000 a year; today it costs approximately $0.03. In 2003, 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 1,000 dollars. The first app appeared in 2008 when Apple founder Steve Jobs enabled outside developers to create applications for the iPhone. Today, just a decade later, the app economy is worth $1.3 trillion,[7] more than the total revenue for the global pharmaceutical market. WhatsApp, which was created

in 2009, sends 55 billion messages a day. News about everything from celebrity gossip – to the latest species extinction – now travels fast.

The World Economic 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 consequences on society as the Fourth Industrial Revolution. It is not only transforming social networks, scientific research and whole industries, it is also radically reshaping biological and material science innovations.

In addition to its transformative effect on industry and society, the Fourth Industrial Revolution is also transforming the opportunity for scientists, researchers and the sustainable development community to address environmental issues, such as biodiversity and habitat loss. This includes exploring how to harness the Fourth Industrial Revolution as a positive force for managing and conserving life on land better, while mitigating the risks that its developments in science and technology might create.

Harnessing these opportunities and proactively managing the risks manifest by the rapid evolution of new science and technologies will inevitably require more creativity and agility in current governance frameworks and financing arrangements. Managing this new agenda successfully will not happen automatically, however. It will require proactive, collaborative processes involving policy-makers, regulators, scientists, civil society, indigenous peoples, entrepreneurs, businesses and investors, among others, working together in new models of cooperation and co-design. Nevertheless, if gotten right, it could create a revolution in the "life on land" agenda that, for the first time in human history, would enable society to realize the full value of nature and catalyse a new, inclusive bio-economy as a result.

The World Economic Forum Fourth Industrial Revolution and the Earth initiative is undertaken with support from the MAVA Foundation, with project adviser support from PwC and Knowledge Partner support from the Stanford University Woods Institute for the Environment. It forms part of the World Economic Forum System Initiative on the Future of Environment and Natural Resource Security.

This thematic paper, which is part of a wider series,[8] explores these issues. Its particular focus is to shed light on how the Fourth Industrial Revolution could help unlock efforts to protect and restore the earth's critical ecosystems and biodiversity hotspots by catalysing a new, inclusive bio-economy that is in line with the targets of Sustainable Development Goal 15, Life on Land, and the Convention on Biological Diversity Nagoya Protocol.[9] It focuses on the Amazon basin as a use case.

This paper is not intended to be conclusive, but rather a stimulant – an overview that provokes further conversation among diverse stakeholders about how the Fourth Industrial Revolution could also usher in a biodiversity and inclusive bio-economy revolution. To this end, the paper will serve as a foundation for further collaborative work as this dynamic new agenda evolves. The World Economic Forum would like to thank all those who collaborated in the production of this paper, in particular Juan Carlos Castilla-Rubio, Founder and Chairman of Space Time Ventures and member of the World Economic Forum Global Future Council on the Environment and Natural Resource Security.

Foreword

Carlos Nobre, Member of the Brazilian Academy of Sciences and Foreign Member of the US National Academy of Sciences, Former Member of Scientific Advisory Board on Global Sustainability of the UN Secretary-General

The earth's biological assets – its plants, animals and the ecosystems they inhabit – are under serious threat. The abundance of the world's wildlife is in steep decline. The *Living Planet Report 2016* estimates that wildlife population numbers are down by an average of 58% since 1970, and are projected to have dropped by 67% by 2020. The earth is currently losing its biodiversity at mass extinction rates. The disruptions of the last few decades look set to continue, putting humanity's own survival, along with those of many other species, at risk.

In the last 12 years, the Amazon basin experienced megadroughts in 2005 and 2010 and megafloods in 2009 and 2012, each with a probability of occurrence of about one in 200 years. The occurrence of so many rare and extreme events in such a short space of time signals a potential change in the status quo of the natural system. Such oscillations between extremes could propel the collapse of the Amazon biome – up to 60% of the Amazon forest could be transformed to degraded savannahs by 2050 due to a combination of deforestation, forest fires and climate change.[11] As the Amazon is home to around half of the world's remaining tropical forests and harbours a large portion of land ecosystems biodiversity, this could have significant implications for the global climate and environment systems. Similar distress signals are also emerging in other natural habitats around the world.

By and large, Amazon development has been unsustainable – relying on accelerated deforestation for beef and grain production. Conservation seems to be on the losing end of such a pathway. A novel development paradigm is needed for the Amazon – a third way – based on an inclusive biodiversity-driven and innovative bio-economy. Ways must be found for the technologies of the Fourth Industrial Revolution to play a transformative role for a new sustainable pathway linking up global research and development capacity with sustainable use of the basin's biodiversity value chains.

The Fourth Industrial Revolution has the transformational power to unlock economic value that was previously inaccessible, by decoding nature's DNA and by learning from its functions and processes. Scientists and entrepreneurs are now able to tap into a new source of knowledge that could be the driver behind the next generation of novel technologies. If the dividends are shared equitably, an inclusive bio-economy could be created that provides a significant new funding stream for conservation and sustainable development efforts centred on the custodians of nature.

The current challenge

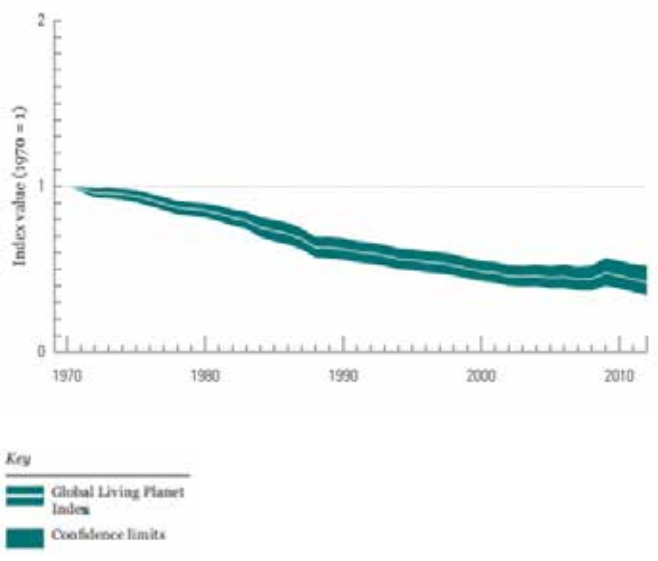
For wildlife

The 2016 International Union for the Conservation of Nature (IUCN) International Congress in Hawaii garnered headlines around the world by drawing attention to startling research that showed the world is currently undergoing a mass extinction event.[12]

Extinction is a natural phenomenon, occurring at a frequency of between one and five species per year – a natural background rate. Today however, the rate of species going extinct is from 1,000 to 10,000 times the background rate, with dozens going extinct every day: a mass extinction event in only one generation.[13]

The Living Planet Index of the environmental organization WWF released at the 2016 IUCN Congress showed an astonishing 58% overall decline in the world's vertebrate population abundance from 1970 to 2012 (Figure 1). During this period, terrestrial populations declined by 38%, freshwater populations declined by 81% and marine populations declined by 36%.[14] This means those born since 2012 have inherited a planet with fewer than half the number of animals on land and below water than those born before 1970. This is a sobering reality.

Figure 1: 58% decline in population abundance, 1970-2012



Trend in population abundance for 14,152 populations of 3,706 species monitored across the globe between 1970 and 2012. The white line shows the index values and the shaded areas represent the 95% confidence limits surrounding the trend.
Source: The Global Living Planet Index, WWF, *Living Planet Report 2016*

For habitats

The main driver for habitat and species loss on land is the destruction of tropical forests for industrial livestock and agriculture. To a lesser extent, infrastructure buildout to support energy generation, oil, gas and mining plays a role.

The world lost a record 29.7 million hectares of tree cover in 2016 – an area about the size of New Zealand. This loss is approximately 51% higher than in 2015.[15] Brazil was a success story between 2004 and 2014 when deforestation dropped by 80%, but the Amazon is under threat again. Deforestation rates are on the rise, principally due to converting forests for pasture and soy (often to feed livestock), which is responsible for more than half of all tropical deforestation in South America.[16]

The loss of tropical forests is important. These habitats are home to more than 80% of all known terrestrial species of animals, plants and insects.[17] The Amazon basin alone comprises at least 15% of the world's land-based biodiversity. Deforestation drives biodiversity loss and species extinction.

The gross domestic product (GDP) of the Amazon basin is estimated at $250 billion per year.[19] On the one hand, this contributes significantly to the economic development of Amazonian countries. However, this economic activity also plays a part in deforestation and forest ecosystem degradation by exploiting water for hydropower, land for soya and cattle, wood for timber, and from the extraction of minerals, oil and gas. The Brazilian Amazon region alone exported $31 billion of commodities in 2014 (the latest available data).[20]

The Amazon basin provides ecosystem services also. It stores an estimated 10 years' worth of global greenhouse gas emissions, removes over 2 billion tonnes of carbon dioxide every year, and presents a mosaic of ethno and linguistic diversity. Its ecosystems harbour a minimum of 15% of the world's land biodiversity. The abundant rainfall in the Amazon generates close to 20% of the freshwater input into the world's oceans.

Given continued deforestation, the frequency of forest fires and climate change, an equilibrium shift could be triggered in the Amazon. Earth system models predict that up to 60% of the Amazon forest could be transformed to degraded savannahs by 2050,[21] with much wider and more catastrophic consequences for the earth's atmospheric circulatory systems.

Indeed, in the last 12 years, the Amazon basin experienced multiple megadroughts and megafloods, each with a probability of occurrence of about one in 200 years. The occurrence of so many rare and extreme events in such a short space of time signals a potential change in the status quo of the natural system. Such fluctuations between extremes could be early signals of collapse of the Amazon biome, and help propel it.

For regional economies

The costs of losing a large portion of the Amazon in 30 years, if it flips to a savannah state, would compromise agriculture and timber production, and significantly diminish the generation of hydropower due to changes in rainfall patterns. More importantly, the loss of species to extinction robs us of the opportunity to learn from the wide array of Amazonian plants, animals and microbes – some of which have not yet been discovered. As the forests are destroyed, stores of greenhouse gas emissions would enter the atmosphere, and the CO_2 sequestration services provided by the Amazon would be beleaguered, leading to more rapid global warming.

Surely the multiple and interconnected risks to the earth of losing the majority of the Amazon to a savannah state are worth more than $250 billion a year for the next 30 years. That's the price tag of conservation of less than 20% of today's annual global app economy.

Yet, the local and international short-run financial gain for agriculture and natural resource commodity players and infrastructure developers outweighs the more abstract regional and global costs - or the long-run risk - of this forest resource one day disappearing. For the individual receiving the short-term financial benefit, this is perfectly rational behaviour. For society both locally and internationally, this is of great concern.[22]

This economic conundrum in the Amazon exemplifies the heart of the challenge of protecting and sustaining our global biodiversity heritage. How can short- versus long-term economic incentives be balanced? How can the needs and rights of indigenous and traditional communities be met while accommodating other public and private stakeholders? And ultimately, how can current versus future generations' interests be properly taken into account?

The challenge of ignoring tomorrow while money can be made today has famously been called the "tragedy of the horizon" by Mark Carney, Governor of the Bank of England and Chair of the Financial Stability Board.[23] More usually, economists refer to this dichotomy as the discount rate, or the social rate of time preference.[24] Our discount rate is generally higher than zero; money put in our pocket today prevails over waiting for money received tomorrow. The higher the discount rate, the more impatient people become for returns today over money tomorrow. Poorer people or people with insecure livelihoods tend to have higher discount rates. For this reason, it makes sense to many "rational" stakeholders to clear the Amazon basin today and worry about tomorrow, tomorrow.

This economic paradigm seems perfectly reasonable if there are many other opportunities to earn a return once today's income dries up. But it seems an irrational assumption if one considers all value at risk, particularly if the sole resource base that provides future economic development opportunities is destroyed.

Thinking about different people's discount rates is a useful insight for looking at environmental challenges like biodiversity. It teaches that the key to the successful stewardship of nature's knowledge endowment is to be found in unlocking local economic solutions – in particular, how to value tropical, biodiversity-rich ecosystems like the Amazon basin in a way that incentivizes the preservation of land over its clearance for resource-intensive income streams. Or, to continue the analogy with the Fourth Industrial Revolution, it shows the importance of unlocking value in the Amazon basin for local people to make it worth even a quarter of the annual global app economy.

This question about the economics of biodiversity has been vexing policy-makers since the seminal 1972 United Nations Conference on the Human Environment in Stockholm.[25] And it is still very much a lively issue. Cracking this question can begin to deliver solutions to biodiversity and habitat loss.

Efforts to preserve biodiversity to date

Through multilateral agreements

The standard international model that has emerged over the past 40 years or so for protecting wildlife and important natural habitats tends *not* to be locally designed. It has taken the form of government-focused, multilateral framework commitments, essentially for protection and conservation. Several were established in particular at the 1992 Rio Earth Summit, such as the United Nations Convention on Biological Diversity (UNCBD), the United Nations Convention to Combat Desertification (UNCCD) and the United Nations Framework Convention on Climate Change (UNFCCC), for example.

They have similar characteristics. They tend to involve a non-binding but time-bound political commitment that governments of the world ("the parties") to the conventions agree to, which is then augmented through efforts to distribute the agreed global goal or goals downward into national and local policies. The CBD Aichi Targets and the Nationally Determined Commitments under the Paris Agreement on climate change are two examples.

These agendas can be supported by complementary global financing mechanisms, like the Global Environment Facility and Green Climate Fund, and more specialized funds and programmatic instruments, such as the pay for performance REDD and REDD+ architecture to slow deforestation, which emerged through the UNFCCC process, or UN Environment Programmes designed to support governments in meeting their relevant convention targets.

Overseas development assistance from richer countries has traditionally provided much of the lifeblood for these mechanisms. Essentially, these government-to-government agreements are trying to "reveal" a price for conservation and then pay that rent to governments that have jurisdictions in biodiversity-rich habitats to avoid destroying them.

This top-down multilateral model for habitat protection has in essence not changed since 1992.

However, rates of tropical forest clearance are increasing, and biodiversity is being lost at mass extinction rates. So, clearly these multilateral mechanisms – while undoubtedly necessary to garner international support – are proving insufficient, at least in their current design, at the local level to fully unlock the economics conundrum.

One key challenge is that these top-down multilateral agreements are designed and promulgated primarily by environment ministries, agencies and international organizations.[26] Consequently, their goals are often perceived by other important public-sector stakeholders to be "nice-to-have" rather than necessary, important or central to national economic growth and innovation in the countries where the habitat lies. As a consequence, their specific targets can suffer from a lack of wider ownership or sense of urgency for aggressive delivery outside of the environment community.

This has been a problem for the biodiversity agenda, exemplified when decisions to protect important habitats or ecosystems get overrun by broader forces and players driving the global economic footprint.

By being public-sector orientated, dependent on international aid and driven mainly by the environment community alone, these multilateral conventions have, arguably, unwittingly limited their potential for innovation, particularly from non-government actors, such as those in the science, business, finance and entrepreneurial sectors, and especially in ways that can transform the market and improve the well-being for local people in developing countries.[27]

Through natural capital approaches

Important efforts have been made over the last few decades to address these limitations in the existing multilateral arrangements and rebalance the economies, notably through the advancement of environmental (and ecological) economics and natural capital analysis. These approaches attempt to help decision-makers reframe how they "value" environmental goods and services and stocks and flows of environmental capital in their economic and financial analyses of projects and policies, and also how environmental externalities, such as pollution, are priced. The Economics of Ecosystems and Biodiversity is a good example of this excellent work.

These efforts have undoubtedly created a much stronger intellectual depth of understanding about the economics of environmental issues and potential trade-offs facing decision-makers. However, they still rely on governments to deliver policy – policy that has environmental costs internalized. And in this agenda, argument is still rife over the discount rate issue. Should decisions involving environmental costs far in the future have their costs discounted more than decisions that might be taken tomorrow?

Over the two decades or so of this intellectual agenda, it is fair to say that environmental economics and natural capital approaches have arguably found it hard to trigger a systemic rethink of mainstream political and economic decision-making, outside of a few specific analyses or programmes.

Once again, given the speed of destruction facing the earth's key biomes, which scientists are now measuring in terms of a few decades (30 years before the majority of the Amazon basin may flip into a degraded savannah state), it could be a risky strategy to focus solely on reorienting economic decision-making practices such that all governments of all political persuasions universally and adequately internalize not only climate change but also biodiversity risks. The speed of policy progress in the universal implementation of adequate carbon pricing mechanisms to change behaviour is a useful case to reflect upon.

Through adjusting incentives

Pulling back from global discussions on biodiversity management and economies, and focusing on the specific land use challenge in the Amazon, two models have historically dominated the realpolitik of national land use decision-making in the Amazon basin regarding the tropical forest. They are:

- A push for valuable nature conservation approaches with large swathes of territory legally protected from any economic and human activity outside indigenous peoples
- A push to convert the Amazon's natural resources for the production of protein commodities (such as meat and soya), using underground resources for minerals, oil and gas, tropical timber at the forest frontier and the buildout of hydropower generation capacity[28]

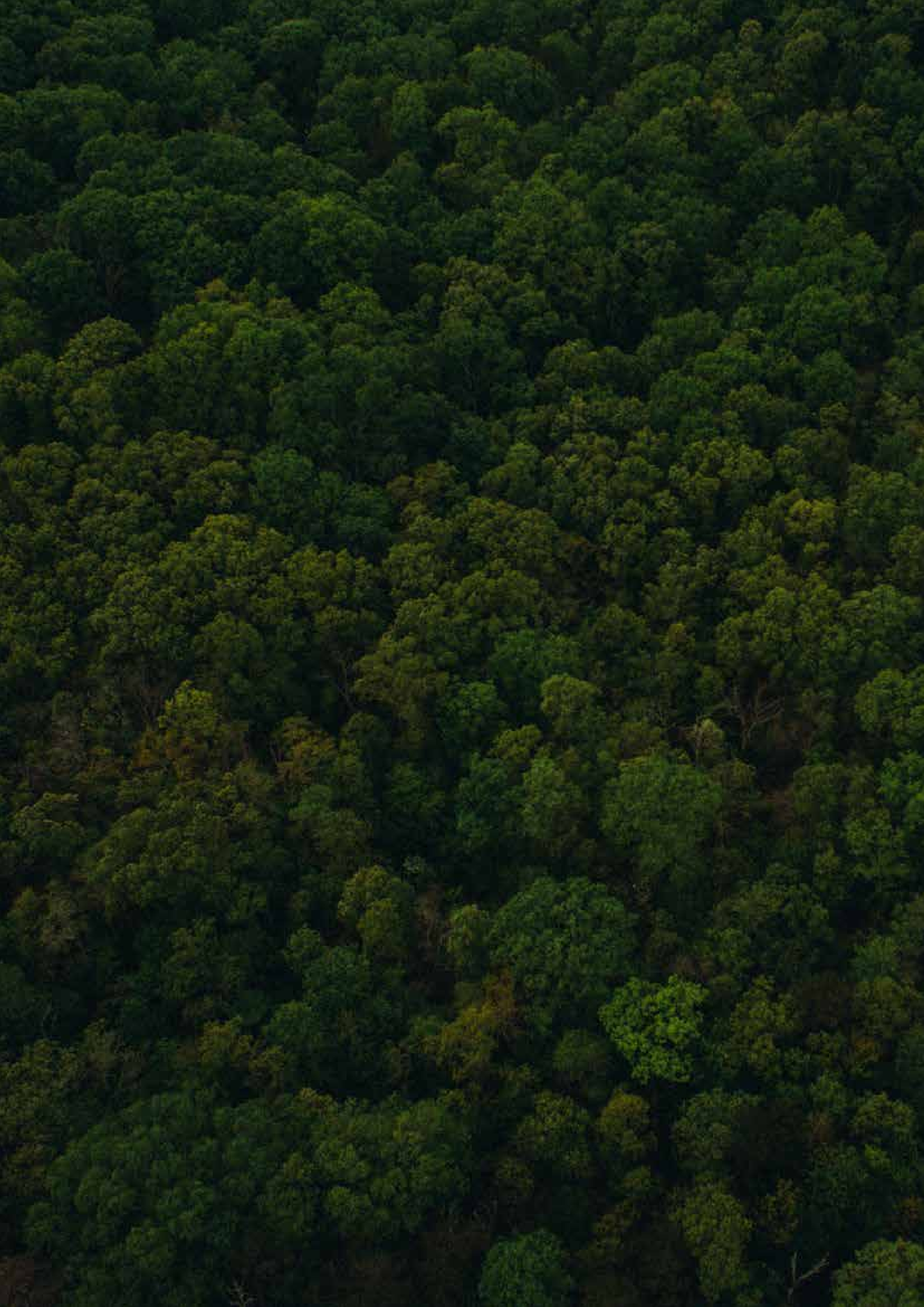
With some successful exceptions, such as the Soy Moratorium in Brazil, the second of these two forces maintains the upper hand domestically because short-run financial gains take precedence. To this end, international conventions, funds and programmes, projects on natural capital and environmental economic valuation, along with pilots in sustainable intensification and agro-forestry systems in degraded land have helped to support and buttress the conservation approaches of national environmental ministries, and helped them hold out against the push for wider forest land conversion.

In the long run, however, it feels like the old English fable of King Canute demanding the incoming ocean tide to turn back. The tide always comes in.

Given the 3 billion new middle-class consumers in emerging markets expected in the next 12 years,[29] it seems the Amazon basin ecosystem will always be converted for short-term economic gain, at least under current circumstances.

This means that even after 40 years of international and regional effort to protect the Amazon, including Brazil's successful reduction of deforestation rates by 80% between 2004 and 2014, the core question at the heart of the biodiversity agenda still seems to be not adequately answered: how to value tropical, biodiversity-rich ecosystems like the Amazon basin in a way that incentivizes the preservation of land over its clearance for resource-intensive income streams.

The need to find alternative models to live with and gain from the Amazon as it stands has become increasingly urgent, and a new opportunity to align incentives is emerging from an unexpected realm.



An unprecedented opportunity from the Fourth Industrial Revolution

Exponential increases in computing power

While the environmental community has wrestled since the 1992 Rio Earth Summit with mainstreaming the importance of the biodiversity agenda, a revolution has been unfolding in the science and technology sector against a backdrop of increasing environmental urgency. Human capacity to capture, store and process data has been transformed to a degree impossible to conceive at the time of the Rio Summit.

The very first web server and browser were created by Sir Tim Berners-Lee in 1990. Email barely existed in 1992, yet today close to 60% of the world's population regularly uses the internet. In 2000, just 12% of the world's population had a cell phone subscription. Now the figure is about 70%. Mobile internet traffic is booming, accelerating at more than 60% per year, an astonishing growth rate when one considers exponential trends. To this end, first introduced in 2007, the smartphone has now become an essential. There are approximately 3 billion smartphone subscribers and about 6 billion smartphones in the world today.

The ever-accelerating growth in processing power is having a profound impact on our ability to collect and process complex data. A standard tablet device today possesses the equivalent processing power of 5,000 desktop computers from 30 years ago. The cost of storing the information these devices produce is approaching zero. For instance, storing 1GB costs an average of less than $0.03 a year today, compared to more than $10,000 20 years ago. This has completely flattened the costs of processing information.

Low cost genome sequencing technology

The first human genome was sequenced in 2001, revealing the building blocks of our DNA in intricate detail. It took more than a decade of work, at a cost of $2.7 billion. That was 15 years ago. Today, a genome can be sequenced in a few hours, for less than $100. Sequencing a gene is like reading a book one letter at a time. It is possible to pick up spelling mistakes – otherwise known as mutations – that increases the likelihood of disease.

The Human Genome Project delivered at least $65 to the US economy for every public dollar spent on the original sequencing, with some estimates rising to $140 and higher. A multitude of genomics industries have been created as a result, and the health sector has been transformed in many ways, leading to precision medicine and other breakthroughs.

Could genome sequencing be harnessed to unlock nature's biological inheritance, honed by evolution over millennia?

Only 14% of the estimated species of plant and animal on land have so far been classified and few (less than 0.1%) have actually had their DNA thoroughly sequenced to understand their potential value, either to the biological system they operate within, or for human-related uses. Indeed, less than 10,000 of nature's 280,000 known natural compounds associated to life on earth to date have been replicated. Just a fraction of the 10-15 million eukaryotic species (plants, animals and single cell organisms) and the trillions of bacteria and other living forms that live on land and in oceans are known.

Yet from this small amount of the earth's biome that humans have so far classified and just the tiny fraction that has so far been sequenced genetically, all the modern knowledge to date in biology and the life sciences has emerged. In turn, this has driven much of the economic value generated each year in agriculture, medicine and bio-based industries, as well as improvements in conservation for endangered species and plants. Annual revenues in the United States alone from genetically engineered plants and microbes are estimated at more than $300 billion, or about 2% of gross US domestic product.[30]

Our knowledge of bio-inheritance containing the collective biological intelligence of 3.5 billion years of evolutionary history is thus shallow, and little of it is leveraged. Biological diversity in the patent system is estimated to include 76,274 species from 23,882 genera in 767,955 patent documents.[31] In other words, innovations involving biodiversity in the global patent system focuses on approximately 4% of all taxonomically described global species and less than 1% of all predicted global species.[32] Clearly, there is still a lot to discover in nature and presumably an immense amount of economic value to be yielded as a result. Provided of course, we don't clear the Amazon and other major biodiversity hotspots first.

The development of a new bio-economy

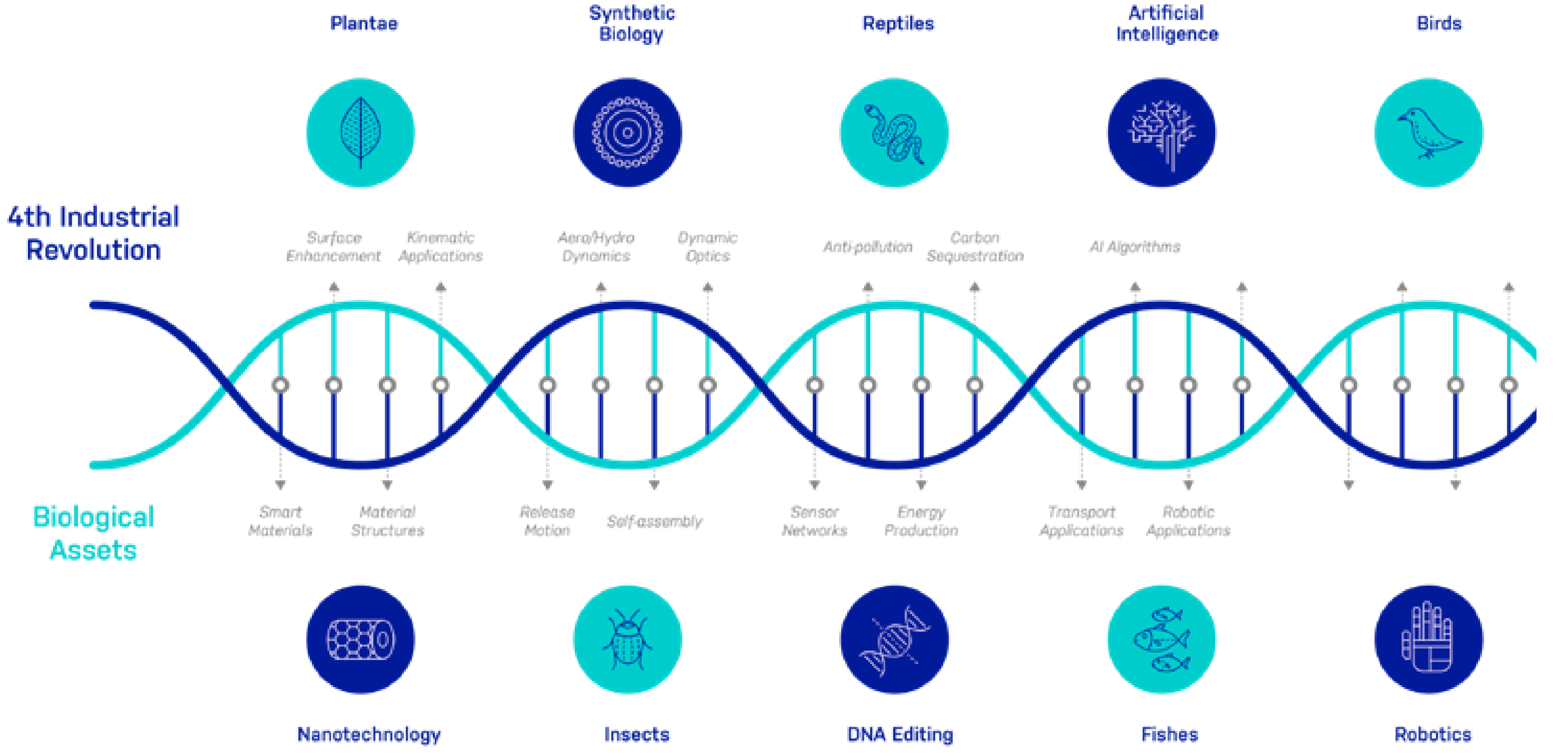
Thus far in all of human history, the ability to understand and harness the full range of nature's bio-chemicals, mirror nature's bio-materials and imitate nature's biological functions and processes has remained relatively limited.

It is only in the last decade or so, with the rise of the Fourth Industrial Revolution, that science and technological innovations have emerged that enable unlocking nature's value. The biology community is experiencing unprecedented acceleration in scientific and technological innovation that is now helping researchers to map, sequence and replicate earth's biological endowment in completely new ways. This is enabling a new "synthetic" biology to emerge, propelling scientists into an uncharted period of powerful and rapid biological design-build-test-learn cycles that may reveal as yet an untold understanding and uses of nature and natural processes. This revolution could help change incentives to preserve our natural capital as an endowment that contains wholly new levels of value for society in the future.

In this new economy, the industry that re-engineers nature, called synthetic biology, was valued at $3.9 billion in 2016 but is growing rapidly.[33] Due to the transformative nature of the Fourth Industrial Revolution, some analysts suggest it could grow to as much as $38.7 billion by 2020[34] and even this could be a very conservative estimate, given how little of nature's secrets we have sequenced thus far.

Figure 2 below exhibits some of these new biology innovations and applications, illustrating how Fourth Industrial Revolution technologies can intersect with biology to derive new bio-economy opportunities.

Figure 2: A new bio-economy powered by the Fourth Industrial Revolution



Source: Authors, The Earth Bank of Codes

Figure 2 shows how interactions between nanotechnology, artificial intelligence, robotics and a myriad of biological innovations are yielding new breakthroughs in smart materials, material structures, energy generation, pollution remediation, and so on. There is a constant, fluid and potentially infinite interaction and innovation frontier between the Fourth Industrial Revolution and nature's assets.

Consequently, and as the Fourth Industrial Revolution gains momentum, a significant new source of economic value and future revenue could be generated by harnessing nature's "biological assets" (its bio-chemicals and bio-materials) and its "biomimetic assets" (its functions and processes). From discovering new drugs to pioneering self-healing concrete, innovation is being accelerated by learning from the processes nature uses and the products it makes.

a. By replicating nature's bio-chemicals and bio-materials

Innovations in the Fourth Industrial Revolution are occurring quickly, so this market is expected to rapidly accelerate in its ability to replicate and utilize nature's bio-chemicals and bio-materials. For instance, one recent breakthrough is the "automated synthesis machine", which combines computational chemistry, robotics and artificial intelligence to rapidly create and analyse new biological assets.[35]

Meantime, a host of start-ups are now integrating computational and robotics technologies to design, engineer and optimize microbes for industrial applications.[36] Methods like these have already helped reduce the market entry time for new bio-products from seven years to two to three years.

The small tree *Pilocarpus microphyllus*, known as jaborandi, is found in the Amazon basin. Jaborandi is used by indigenous communities to treat mouth ulcers, colds and the flu. The earliest reports referring to these traditional knowledge assets date back to the 16th century. Over the last few years, jaborandi was found to induce both sweating and salivation, knowledge that led to the development of the *Imidazole Alkaloid Pilocarpine*, which is used in the FDA-approved drug Timpilo for treating glaucoma eye disease.[37] This is a good example of Fourth Industrial Revolution techniques and new biology working together to rapidly unlock the value from a biological asset. Historically, it would have taken over a decade of painstaking biology benchwork and trials in laboratories, and hundreds of millions of dollars, to derive value from such an asset. Often the risk would offset the benefit and the investment wouldn't be made. Now, smaller entrepreneurial ventures can engage, widening the innovation marketplace and accelerating the pace of bio-inspired innovation.

With the declining effectiveness of last-line antibiotics, many governments believe anti-microbial resistance will rise to become the top public health challenge of the 21st century.[38,39] Experts estimate that deaths from drug resistance could increase from hundreds of thousands of cases today to 10 million per year by 2050, causing a drop in global GDP of between 2% and 3.5%, or a loss of up to $100 trillion.[40]

Could the Amazonian giant monkey frog contribute to solving this crisis? The frog (*Phyllomedusa bicolor*) secretes a liquid full of peptides that has been historically used by indigenous communities in the west and south-west of the Amazon basin. Their effects include increased stamina and alertness. They have prompted extensive pharmacological studies[41] that have identified these frogs as a store of valuable bio-active compounds that could hold the key to the next generation of antibiotics and other valuable pharmaceuticals.

Indeed, frogs from all over the world will become increasingly valuable. A case in point is a recently de-codified antiviral peptide from an Indian frog that may be the first line of defence in a future influenza A pandemic, to be used before the necessary vaccines are developed.

This, at a time when frogs are critically endangered. The world has lost over 200 species of frog since the 1970s and hundreds more will face extinction in the coming decades as a result of a deadly invasive chytrid fungus. Some experts estimate that at least 10% of all frogs will be lost by 2100.[42]

Phyllomedusa bicolor frog
Source: 2002 Jean-Marc Hero

b. By replicating nature's functions and processes

Scientists and entrepreneurs are also honing their ability to harness the Fourth Industrial Revolution and new biology techniques to identify and replicate nature's biomimetic assets (its functions and processes).

Biological systems in nature are the result of billions of years of evolution. Biomimetic asset innovations focus on learning from and then emulating natural forms, processes and ecosystems to create more sustainable designs and innovations. With advances from the Fourth Industrial Revolution, scientists are rapidly gaining understanding[43] about how nature builds (materials), how organisms interact with their surroundings (sensors), how they move in their environment (biomechanics and kinetics) and how they behave and function (processes).

The innovation potential is significant in biomimetic-enabled nanoscience to support environmentally friendly pollution prevention and remediation technologies, bio-inspired textile structures, renewable energy production, carbon sequestration and storage, and behavioural and cognition-artificial intelligence robotic applications, to mention but a few.

Cost-efficient artificial photosynthesis holds potential for removing carbon dioxide from the atmosphere at scale. In 2017, based on biomimetic studies using new biology and Fourth Industrial Revolution techniques, Harvard scientists developed an artificial leaf that pulls carbon from the air four times more efficiently than the fastest growing plant.[44]

This bio-inspired industry is at the early stages of development; as it matures, it could further transform the economic value ascribed to nature. The possibilities seem enormous, particularly in light of our urgent need for solutions as climates change.

Studies of the ant *Eciton burchelli* found in the Amazon using Fourth Industrial Revolution techniques in artificial intelligence have identified that the species uses "swarm intelligence" to ensure their worker ant army, numbering in the hundreds of thousands, avoids any form of traffic congestion or unwarranted collision. Studying and digitizing how fluid ant traffic systems work are inspiring the development of artificial intelligence algorithms for autonomous, shared and electric power transport systems for safe, congestion-free cities of the future.

Thus the Fourth Industrial Revolution can usher in an accelerated and suitably wide-scale innovation agenda for scientific research coupled with an entrepreneurial revolution to unlock potential value from ecosystems like the Amazon basin. How would this be operationalized? And how then could this be used to adjust the incentives of local and international stakeholders towards the protection of these natural assets, in light of the short-run benefits of land conversion and resource extraction?

Eciton burchelli ant
Source: Geoff Gallice

Towards an inclusive bio-economy

"We have our deepest hopes in technology, but our deepest trust in nature."
– *W. Brian Arthur, External Professor, Santa Fe Institute, USA*

As much as this Fourth Industrial Revolution is changing how people shop, drive or book a hotel room, it is also transforming the ability of biologists and ecologists to understand nature and – as a result – to at last unlock the value to be gained from it. Now, in light of developments in genomics, blockchain and artificial intelligence, it may also be possible to protect these natural assets.

The Earth BioGenome Project

The Human Genome Project was revolutionary in its aspiration in 1988 when the project was first conceived. Today the Earth BioGenome Project (EBP) aims to sequence all the plants, animals and single-celled organisms on earth (the eukaryotic species) within 10 years, to help unlock the vast potential of our biodiversity inheritance. The EBP has been likened to the Human Genome Project both in its ambition and for the myriad of benefits it hopes to bring to biological research and to the biodiversity, conservation and related bio-industry agendas.[46]

The EBP offers a systems-level transformation in biological science and biodiversity management. It has a broad mission, aiming to create the new foundation for biology that drives solutions for preserving earth's biodiversity, managing ecosystems, spawning bio-based industries and sustaining human societies.

The goals of the EBP are supported by some of the world's leading universities and research centres, in addition to the Smithsonian Institution in the United States, the Beijing Genomics Institute (BGI) in Shenzhen, China, the Wellcome Trust Sanger Institute and the Royal Botanical Gardens in the United Kingdom, the FAPESP (São Paulo Research Foundation) in Brazil and the U.S. Department of Agriculture in the United States, and the list of partners is rapidly expanding. The EBP is working closely with the Global Genome Biodiversity Network,[47] the Earth Bank of Codes[48] and a number of biotech and Fourth Industrial Revolution innovation start-ups.[49]

The project is now possible because the cost of genomic sequencing has dropped exponentially. In addition, hand-held DNA sequencers, for example, are revolutionizing low-cost sequencing in the wild. The potential is significant to on-board these new miniaturized sequencing technologies in autonomous air-, land- and ocean-faring drones to speed up increased specimen capture and sequencing.

The details are still being worked out but, as currently proposed, the first step would be to sequence the DNA of a member of each eukaryotic family (about 9,000 in all) to create reference genomes on par or better than the reference human genome and the 23,000 IUCN species at risk of extinction, starting in the Amazon basin. Over time, the genomes of the 1.5 million remaining known eukaryotic species would be sequenced. These lower resolution genomes could be improved as needed by comparing them with the family references or by doing more sequencing.

The $4 billion needed to run the Earth BioGenome Project that is additive to existing and ongoing scientific research in genomic sequencing will need to be financed. In addition, the universal policy, governance and data sharing principals and protocols will need to be developed in unison with the research, to help ensure that the risks to society from the project to sequence all life on earth are minimized, the opportunities for societal benefit are maximized, and the fair and equitable sharing of benefits is operationalized. The project will rely on convening multistakeholder collaborations that draw in science, research, technology and ethics communities, along with governments and the private sector.

The bio-piracy challenge

The confluence of Fourth Industrial Revolution technologies and new biology helps to identify a tangible alternative source of economic value. However, incentivizing the conservation of critical biomes like the Amazon requires the fair sharing of benefits generated from the sequencing of nature's biological and biomimetic assets with local actors. Unfortunately, this has not always been the case.

A deep-rooted societal fear of bio-piracy is of concern to developing countries (whether or not the act is intentional). Its roots go back to the mid-19th century and the "theft" of rubber tree seeds from the Amazon basin by the British, which gave rise to the plantations in South-East Asia and the demise of the rubber boom in the Amazon early in the 20th century.

At the heart of the bio-piracy agenda lies the juxtaposition of dramatically different value systems, cultural contexts, world views of trade, intellectual property and the rights of indigenous knowledge. Indigenous peoples with custodial rights over land, plants or animals and the knowledge related to them do not hold those rights in the same manner as a patent or intellectual property asset. Rather, traditional knowledge is tacit and implicit, something that is socialized across communities and through generations.

In a world of synthetic biology, how will the value derived from the genetic sequencing of nature's assets be shared with the world's biodiverse nations and their respective indigenous and traditional communities, who have historically missed out on returns from such innovations? And will the transition occur quickly enough to incentivize the protection of these resources now, at this critical juncture?

The answer lies in creating a "bank" of codes, tasked with housing this wealth of knowledge and ensuring the fair and equitable sharing of the benefits arising from bio-inspired innovations.

A solution: The Earth Bank of Codes

The proof of concept for the Earth BioGenome Project will be located in the Amazon – in light of the rich biodiversity it houses and the impending threats it faces. The product will be the Amazon Bank of Codes (ABC), which will provide an open, global public good and digital platform that registers and maps the genetic sequences of Amazonian biodiversity. By registering biological and biomimetic intellectual property (IP) assets on blockchain, this code bank will record the provenance, rights and obligations associated with nature's assets to track their provenance and use. When value is created from accessing these assets, smart contracts would facilitate the fair sharing of benefits to the custodians of nature and for its protection. Following this proof of concept, an Earth Bank of Codes would facilitate a similar approach in other key biomes on land and in the oceans, such as the Congo basin.

The ABC could provide the Fourth Industrial Revolution the key that unlocks the door to making the new bio-economy for the Amazon basin inclusive and economically meaningful for the local stakeholders who live in and rely on the ecosystem. Leveraging the thinking of economist Hernando de Soto, the ABC could provide an immutable community asset, which indigenous and traditional communities can leverage to create wealth and improve their own well-being. It is an asset based on the biological, biomimetic and traditional knowledge assets of the ecosystem and their relationship with it. Currently unvalued and therefore untradeable, the confluence of the Fourth Industrial Revolution and new biology can yield a value for their wealth, which can now enter the local, national and global markets for innovation.

By providing an alternative source of income to local communities and dedicating funds for the preservation of nature, local incentives will shift to maintain these complex ecosystems. Indeed, why destroy an asset that could reveal further value as the Fourth Industrial Revolution unfolds?

Ultimately, bio-innovators worldwide would tap into a store of data that accelerates the likelihood of scientific breakthroughs with a one-stop-shop for nature's assets from biomes around the world. A fair share of the economic value created from such breakthroughs would automatically be returned to the custodians of the various components of these source assets. Indeed, innovators could be certified through blockchain for the sustainable sourcing of nature's assets.

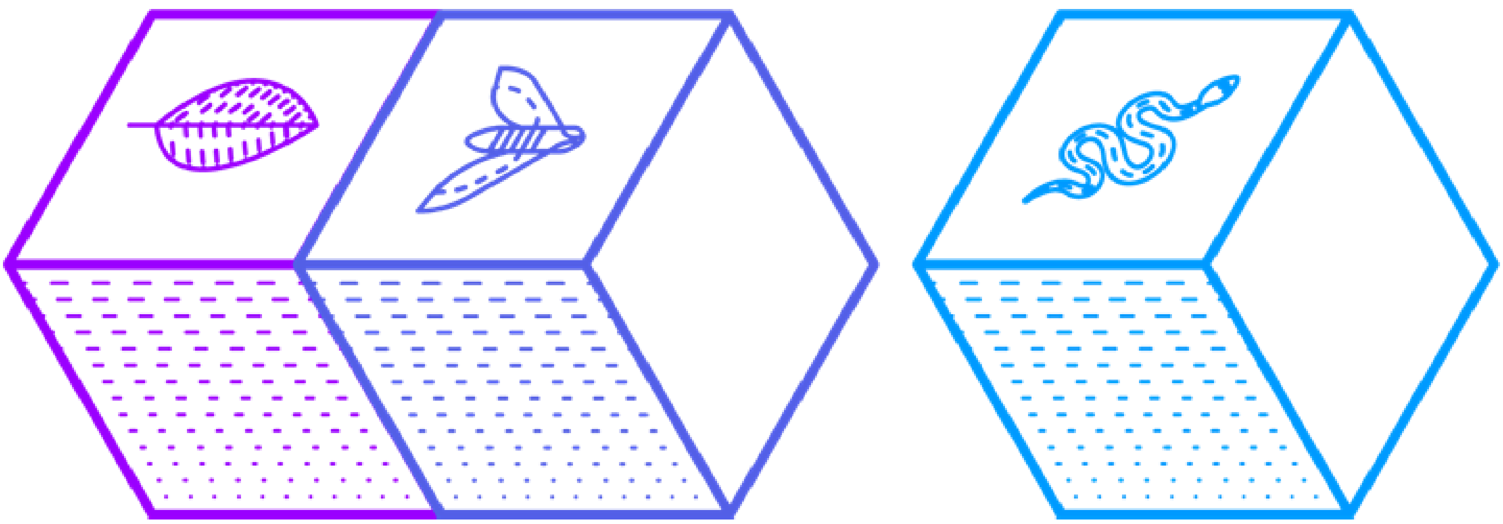
The value could be immense for indigenous and local communities. The ability for wealth to channel directly to nature's custodians along with the resources for conservation offers efficiencies and fairness. At the same time, this mechanism helps shift local incentives away from short-term clear-cutting towards longer-term preservation.

In this way, the partnership between the Earth BioGenome Project and the Earth Bank of Codes has the potential to facilitate the implementation of the Convention on Biological Diversity (CBD) Nagoya Protocol, and help redraw several components of the CBD itself, in time for the COP 15 of the CBD and the Conference of the Parties to its protocols in China in 2020 – when new targets need to be agreed upon.

The partnership between the Earth BioGenome Project and the Earth Bank of Codes will be launched at the World Economic Forum Annual Meeting 2018 in Davos-Klosters.

a. How would a Bank of Codes work?

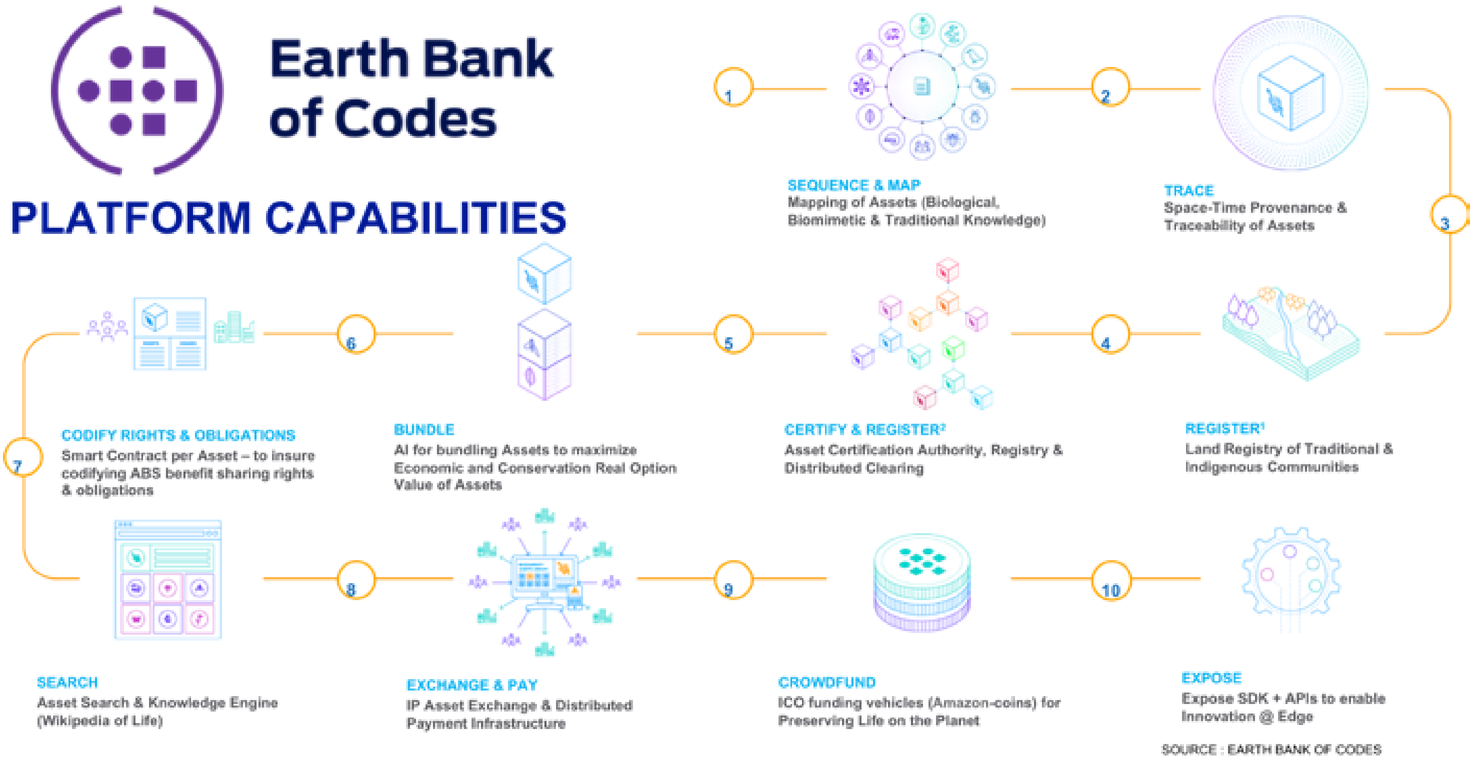
The Amazon basin is a good proof-of-concept for the Earth Bank of Codes as it encompasses a minimum of 15% of the world's land biodiversity and more than 30% of eukaryotic families.



The goal of the Amazon Bank of Codes (ABC) is to make the current and future value of Amazonian biological, biomimetic and traditional knowledge assets visible. By creating higher economic incentives in local communities to protect the Amazon's biodiversity, its forests would be conserved and rivers kept flowing.

Looked at in another way, the ABC can be seen as an initiative that offers the means to indigenous and traditional communities and local actors in the Amazon basin, as well as the CBD at the international level, to eliminate bio-piracy in a practical manner, using Fourth Industrial Revolution technologies like blockchain.

Figure 3: The Amazon Bank of Codes platform architecture



Source: Authors, The Earth Bank of Codes

The 10 capabilities of the Amazon Bank of Codes are:
1. SEQUENCE AND MAP: Map the genetic sequences, the biomimetic assets and the traditional knowledge assets in the Amazon basin, thereby providing unique digital identities
2. TRACE: Provide traceability and the spatial and temporal provenance of the traditional knowledge and biological and biomimetic assets that have been sequenced and mapped
3. REGISTER: Register the indigenous and traditional community lands onto a system compatible with ABC; this will be done in partnership with governments and as a result of governments realizing and supporting the economic, environmental and social benefits ABC will bring to local communities and the jurisdiction
4. CERTIFY AND REGISTER: Immutably register and certify these traditional knowledge, biological and biomimetic knowledge assets on blockchain
5. BUNDLE: Develop an AI-driven optimal "bundling" of biological, biomimetic and traditional knowledge assets, such that both the economic *and* the conservation value from using assets can be maximized
6. CODIFY RIGHTS AND OBLIGATIONS: Codify rights and obligations through smart contracts associated to the commercial use of the traditional knowledge, biological and biomimetic assets to ensure fair and equitable benefit sharing (leveraging the Convention on Biological Diversity Access and Benefit Sharing Protocol)
7. SEARCH: Build a biological asset search and knowledge-sharing engine; it will be designed as an open platform so the knowledge-sharing engine can develop into a Wikipedia of Life, as users share innovations and ideas
8. EXCHANGE AND PAY: Develop a Commercial IP Asset Exchange and Distributed Payment Infrastructure to reduce the transaction costs of all involved, and to ensure that the commercial players who are obliged to share the benefits arising from nature's knowledge assets can pay directly to the originators of those assets, and to contribute to fund conservation efforts and the enabling research and digital infrastructures
9. CROWDFUND: Raise funds, potentially through initial coin offerings, to help finance the development and scaling of the platform
10. EXPOSE: Ensure the democratization dimension of the ABC by exposing its software development kit and its application programmable interfaces to enable cutting-edge social and commercial entrepreneurs to gain access to the ABC and thereby speed up their innovation life cycles

These steps may not be sequential; however, they are all required to offer a comprehensive platform as a use case. The ABC would be sprint-built, rapidly creating a mock-up prototype as a working pilot for demonstration during the first half of 2018.

Initial discussions are under way with experts from the World Economic Forum Network of Global Future Councils and leading partners in science and technology to support the Amazon Third Way Initiative's buildout. Support from other organizations is invited, especially from interested philanthropists, foundations and international organizations.

b. How would nature's assets be traced?

From a technology perspective, identifying the origins of genetically modified molecules and sourcing them back to the correct local community will be an interesting challenge to overcome. Genetic information is often combined or modified with samples from multiple species and sourced from various genetic sequence libraries. In some cases, new molecules are produced using the natural processes from other organisms.

For example, it is not uncommon to combine six different genes from six different species from around the world, which can then be inserted in a seventh species (like yeast) with the aid of synthetic biology to develop a valuable pharmaceutical in a bio-refinery in São Paulo, Shanghai, Palo Alto or Boston.

Consequently, when it comes to distributing the financial benefits, the use of open-access DNA databases and proprietary libraries of biological parts around the world will necessarily make things complex. Work will be required with biologists, innovators, regulators and ethicists to create coding frameworks for assigning fair attribution.

In addition, genetic information can currently be transferred easily across national borders in sample form, and the physical specimen is often not needed for research and development. Biomimetic assets, which are the biological functions and processes used by nature, face an additional hurdle in that no Nagoya Protocol equivalent exists for this intangible asset class. Again, further work will be needed in this area, including with digital trade experts.

c. How might a Bank of Codes be deployed?

From the government perspective, the ABC can be viewed as an innovative "regtech" (regulatory technology) platform. It would support national governments and states in Amazon-basin countries to implement the Nagoya Protocol, which aims to ensure the fair and equitable sharing of benefits arising from the use of genetic resources. Importantly, the platform would represent a broad-based partnership between the Amazonian nations' biodiversity regulatory authorities and multistakeholder coalitions. By unlocking significant economic value from the Amazon basin, an inclusive bio-based economy is feasible for the first time in history.

To this end, the ABC will implement a group of pilots, in cooperation with government biodiversity regulators and leading research and development organizations in the Amazon and internationally, and in close partnership with indigenous and traditional communities.

A suggested approach to trial the ABC could be to create a dedicated public-private academic-sector coalition that is committed to testing the concept in a designated area with local indigenous and traditional communities, using a so-called regulatory sandbox approach. A regulatory sandbox is a framework originally set up by financial-sector regulators to allow small-scale, time-bound, live testing of innovations in a controlled environment under the purview of the regulator, while allowing room for trial and innovation. Ideally, a pilot would include multiple jurisdictions so overlapping or conflicting regulations can be addressed early on.

The goal will be to allow all stakeholders to be facilitated by an iterative pilot project process to work together to co-design and co-test these innovations, while allowing policy-makers and regulators to learn, in order to ensure appropriate safeguards and better defined future regulation for these innovations. Rapid prototyping and iteration will be key to identify and close policy bottlenecks and gaps. In this way, a pilot platform for the ABC can be co-developed and co-tested in time to inform the CBD COP 15 in Beijing in 2020. Ultimately, the approach could be replicated in other key biomes on land and in the oceans, such as in the Congo basin or Great Barrier Reef.

Building the enabling environment

An unprecedented opportunity is on our doorstep

The Earth BioGenome Project in partnership with the Earth Bank of Codes offers a vision for an open, global, public-good platform that could unlock untold economic value from nature's assets. By registering the origins, the rights and the obligations associated with these resources and tracing their use in innovation value chains, the fair and equitable sharing of benefits can be ensured.

This inclusive bio-economy would align incentives between indigenous and traditional communities, biodiversity-rich nations and innovators to safeguard the natural heritage now and in the future. Why clear-cut forests now if they can offer income today? As for the future, the exponential acceleration of the Fourth Industrial Revolution means that natural assets could be unlocked further as technology advances and an understanding of biology and biomimicry improves.

The bio-inspired revolution outlined in this paper could be catalytic for the conservation agenda also. Funding flowing from these new income streams could provide an important new source of revenue to preserve ecosystems on the local and national levels around the world – where they are needed most.

Incentives can be aligned to protect rather than destroy our natural heritage

Tropical, biodiversity-rich ecosystems like the Amazon basin could become more valuable to local people each year if left in their natural state rather than cleared to generate income from resource-intensive industries. As the attribution of value changes, so incentives shift. At last, a sustainable option on the table offers value to all without compromising the integrity of our natural systems.

How then can an enabling environment be built to ensure this inclusive bio-economy has a chance to offer an alternative to multitrillion-dollar land- and resource-intensive sectors worldwide?

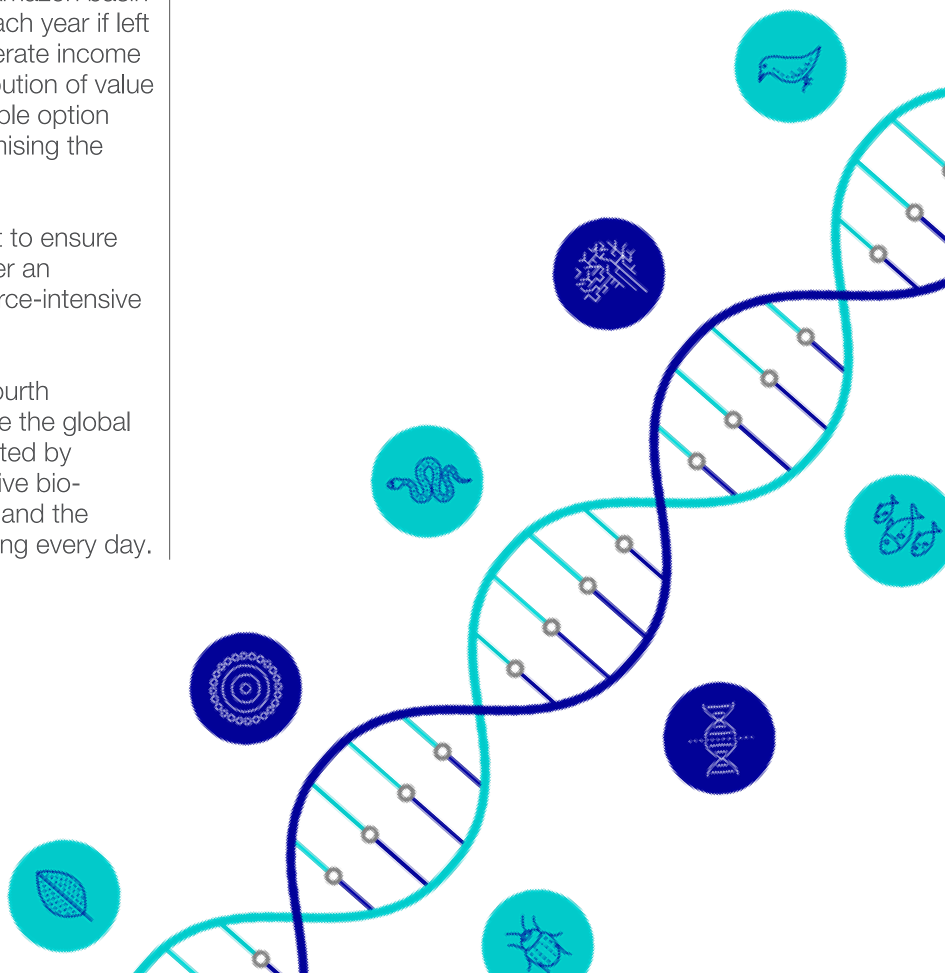
Exponential change is a characteristic of the Fourth Industrial Revolution. Trillion-dollar industries like the global app economy have appeared overnight, facilitated by technological advances. The case for an inclusive bio-economy is no different. The technology exists and the speed at which it can be deployed is accelerating every day.

Rapid multistakeholder partnerships are needed now

Complexity lies *not* in the deployment of technology but in governance systems, diverse interests and cross-border protocols that govern this new inclusive bio-economy. The development of the Earth Bank of Codes needs to imbed within it human values and account for the various needs of local, national and international stakeholders. In particular, the approach would need to build the trust of historically disenfranchised indigenous and traditional communities.

The World Economic Forum System Initiative on the Future of Environment and Natural Resource Security will provide its platforms and networks, if and when helpful, to support and advance the development of the Earth Bank of Codes in its partnership with the Earth BioGenome Project, as an associated workstream of its Fourth Industrial Revolution for the Earth initiative. Driven by the potential that the Fourth Industrial Revolution offers, public-private innovations like these create new models and impetus for cooperation in managing our global environmental commons. Together it seeks to work with stakeholders on the local, national and international levels to refine and develop this initiative.

As humanity faces a mass extinction event on a scale not seen in the last 65 million years, time is of the essence. The Fourth Industrial Revolution holds the keys to fundamentally altering the way people understand and interact with their natural environment. Without rapid, coordinated action, the lifeboat that the Fourth Industrial Revolution presents to pull our planet back from the brink may be missed.



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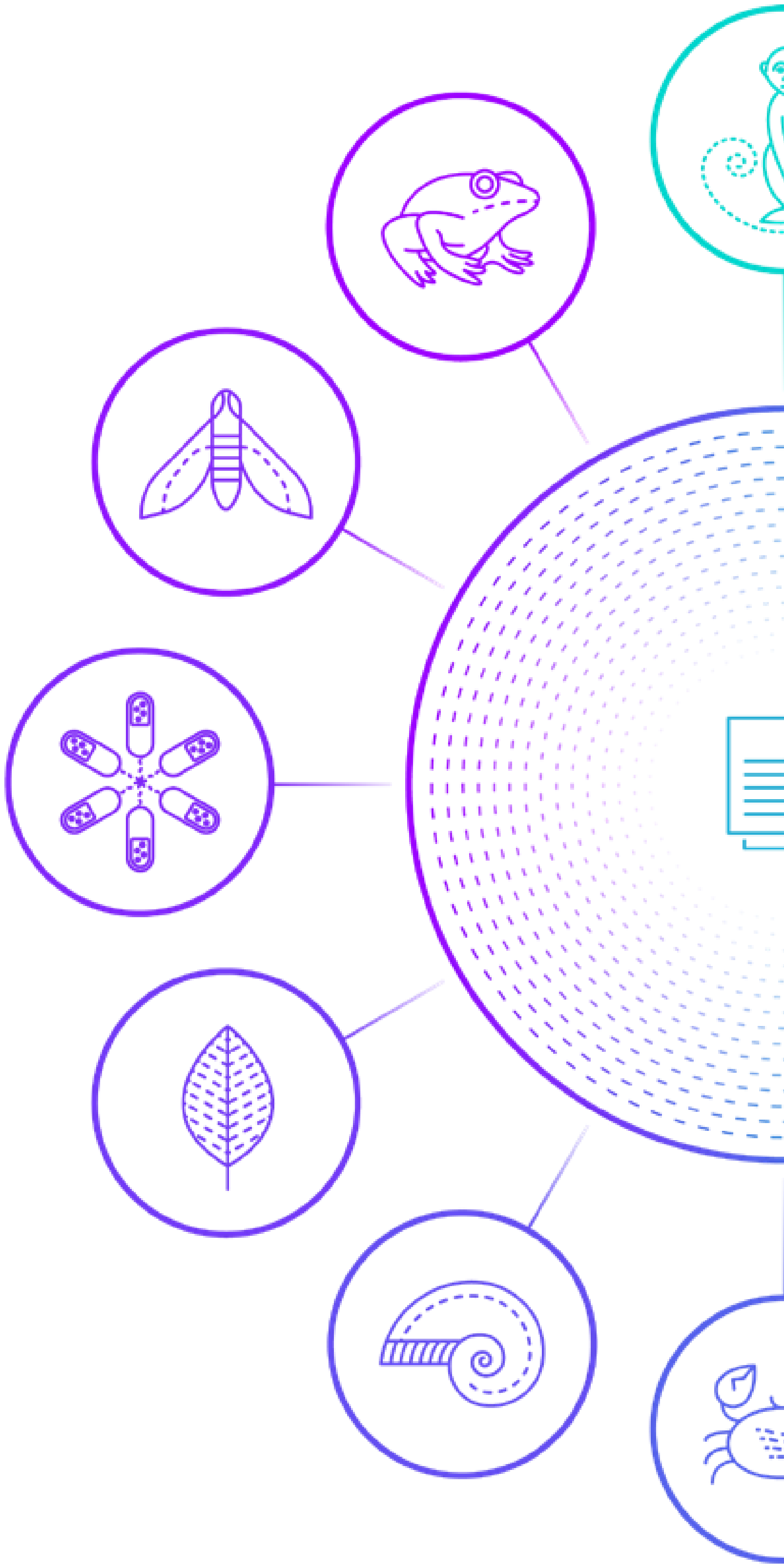

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About the Fourth Industrial Revolution for the Earth initiative

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 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 World Economic Forum and its Center for the Fourth Industrial Revolution in San Francisco. It also brings the Stanford University Woods Institute for the Environment's researchers and their networks in the 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 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 are provided as background and are not intended to be exhaustive.[50]

- **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 and autonomous vehicles**. Enabled by robots, vehicles that 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, a technology set that has applications in areas like energy, material, chemical, pharmaceutical, agricultural and medical industries.
- **Energy capture, storage and transmission**. New energy technologies that range from advanced battery technologies 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 (IoT)**. 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**. 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 World Economic Forum 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 World Economic Forum, supported by Stanford University and PwC (as project adviser) and advised by the members of the Global Future Council on the Environment and Natural Resource Security and specific Fourth Industrial Revolution technology 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 that the Fourth Industrial Revolution offers
- Design a **public-private accelerator for action**, enabling government, foundational, research organizations 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 to take hold and develop

The Fourth Industrial Revolution for the Earth initiative will be driven jointly from 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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47. BGI was founded in 1999 with the vision of using genomics to benefit mankind and has since become the largest genomic organization in the world. With a focus on research and applications in the healthcare, agriculture, conservation and environmental fields, BGI has a proven track record of innovative, high profile research, which has generated over 2,137 publications, many in top-tier journals such as *Nature* and *Science*. The Wellcome Trust Sanger Institute is a world leader in genome research and aims to deliver new insights into human and pathogen biology that change the course of biology and medicine. Their mission is to use genome sequences to increase understanding of human and pathogen biology in order to improve human health. The Global Genome Biodiversity Network (GGBN) is an international network of institutions that share an interest in the long-term preservation of genomic samples that represent the diversity of non-human life on earth. GGBN provides a platform for biodiversity biobanks from across the world to collaborate and ensure consistent quality standards for DNA and tissue collections; improve best practices for the preservation and use of such collections; and harmonize the exchange and use of material in accordance with national and international legislation and conventions. The GGBN's efforts to compile genetic resources at museums and other bio-repositories around the world can help supply much of the DNA required by the Earth BioGenome Project.
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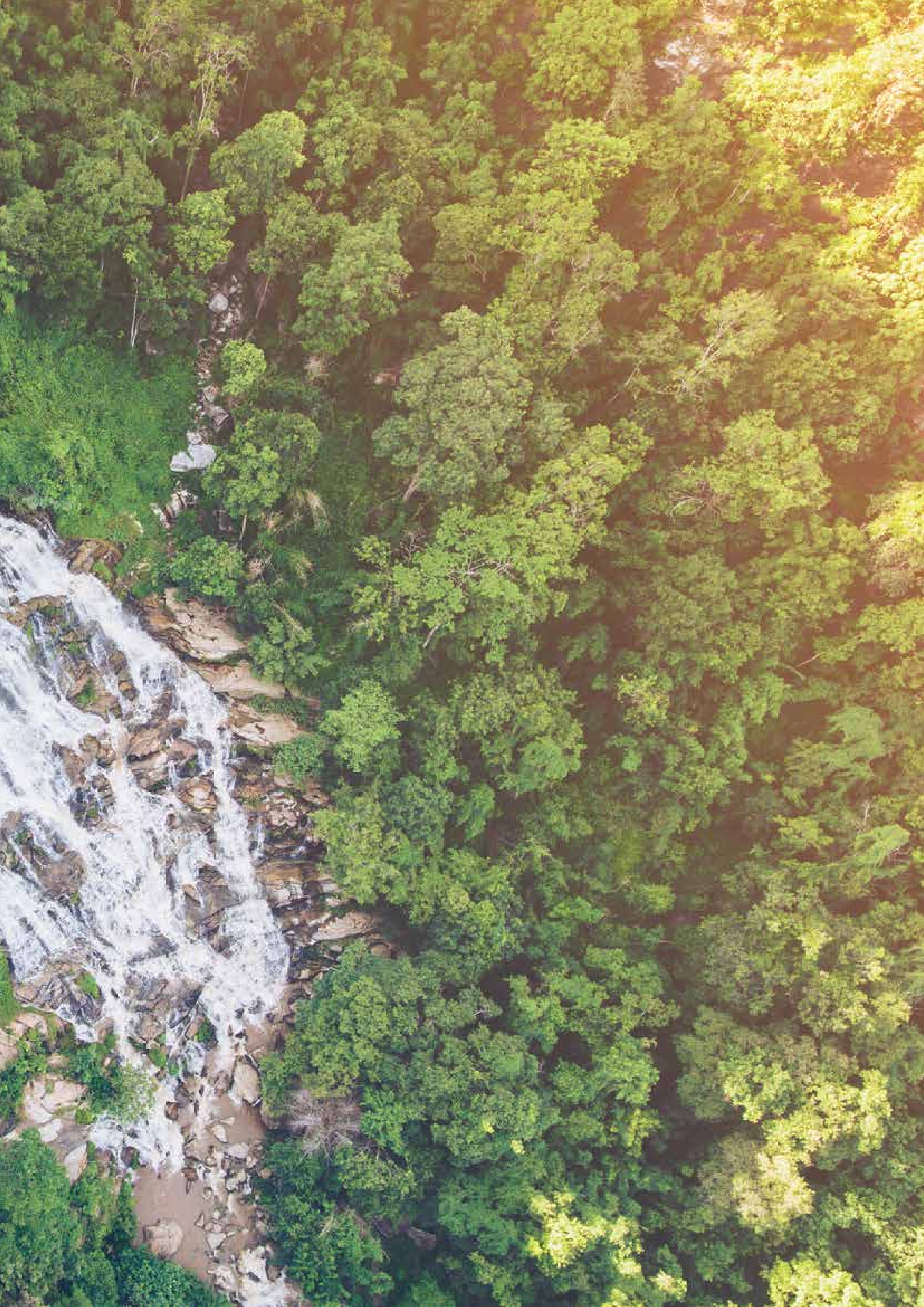

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