Fourth Industrial Revolution for the Earth Series

Building block(chain)s for a better planet

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pwc

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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 multistakeholder collaboration.

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The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation. The Forum engages the foremost business, political and other leaders of society to shape global, regional and industry agendas.

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Preface

The Fourth Industrial Revolution and the Earth

The majority of the world's current environmental problems can be traced back to industrialization, particularly since the "great acceleration" in global economic activity since the 1950s. While this delivered impressive gains in human progress and prosperity, it has also led to unintended consequences. Issues such as climate change, unsafe levels of air pollution, depletion of forestry, fishing and freshwater stocks, toxins in rivers and soils, overflowing levels of waste on land and in oceans, and loss of biodiversity and habitats are all examples of the unintended consequences of industrialization on our global environmental commons.

As the Fourth Industrial Revolution (4IR) gathers pace, innovations are becoming faster, more efficient and more widely accessible than ever before. Technology is becoming increasingly connected, and we are now seeing a convergence of the digital, physical and biological realms. Emerging technologies, including the Internet of Things (IoT), virtual reality and artificial intelligence (AI), are enabling societal shifts as they seismically affect economies, values, identities and possibilities for future generations.

There is a unique opportunity to harness the Fourth Industrial Revolution – and the societal changes it triggers – to help address environmental issues and transform how we manage our shared global environment. Left unchecked, however, the Fourth Industrial Revolution could have further unintended negative consequences for our global commons. For example, it could exacerbate existing threats to environmental security by further depleting global fishing stocks, biodiversity and resources. Furthermore, it could create entirely new risks that will need to be considered and managed, particularly in relation to the collection and ownership of environmental data, the extraction of resources and disposal of new materials, and the impact of new advanced and automated machines.

Harnessing these opportunities and proactively managing these risks will require a transformation of the current "enabling environment" for global environmental management. This includes the governance frameworks and policy protocols, investment and financing models, the prevailing incentives for technology development, and the nature of societal engagement. This transformation will not happen automatically. It will require proactive collaboration among policy-makers, scientists, civil society, technology champions and investors.

If we get it right, it could create a sustainability revolution.

Working with experts from the environmental and technology agenda, the "Fourth Industrial Revolution for the Earth" project is producing a series of insight papers designed to illustrate the potential of Fourth Industrial Revolution innovations and their application to the world's most pressing environmental challenges. Collectively and individually, these papers offer insights into the emerging opportunities and risks of this fast-moving agenda, highlighting the roles various actors could play to ensure these technologies are harnessed and scaled effectively. The papers are not intended to be conclusive, but rather to act as a stimulant – providing overviews that provoke further conversation among diverse stakeholders about how new technologies driven by the Fourth Industrial Revolution could play a significant role in global efforts to build environmentally sustainable economies, helping to provide foundations for further collaborative work as this dynamic new agenda evolves. This particular paper looks at blockchain and the Earth. Previous papers in the "Fourth Industrial Revolution for the Earth" series have looked at how the Fourth Industrial Revolution could transform ocean management, enable sustainable cities, and build an inclusive bio-economy that preserves biodiversity, as well as examining how artificial intelligence could be harnessed to address economic, social and governance challenges related to Earth systems.

Foreword

Blockchain[1] is a foundational emerging technology of the Fourth Industrial Revolution, much like the internet was for the previous (or third) industrial revolution. Its defining features are its distributed and immutable ledger and advanced cryptography, which enable the transfer of a range of assets among parties securely and inexpensively without third-party intermediaries. It is also democratized by design – unlike the platform companies of today's internet – allowing participants in the network to own a piece of the network by hosting a node (a device on the blockchain). Blockchain is more than just a tool to enable digital currencies. At its most fundamental level, it is a new, decentralized and global computational infrastructure that could transform many existing processes in business, governance and society.

Blockchain has received considerable hype, ranging from "cryptomania" in the trading markets in 2017 to widespread discussions about the breadth and depth of its potential impact across public and private sectors and society in general. It has also invited scepticism related to its scalability and the high-energy use of early blockchain platforms.[2] As of early July 2018, the total cryptocurrency market cap (spanning 1,629 currencies) stands at about $254.67 billion.[3] As the architecture for this transformational technology matures and as both the blockchain hype and scepticism begin to rationalize, there is a significant opportunity to shape how blockchain is developed and deployed.

A number of blockchain applications and platforms are becoming widely known, starting with Bitcoin, which pioneered cryptocurrency (and crypto-assets), followed by Ethereum, which as a platform for building decentralized applications through smart contracts has inspired a whole new "token economy". The emergence of applications in voting, digital identity, financing and health illustrate how blockchain can potentially be used to address global challenges.[4] There is now also emerging enthusiasm about blockchain's potential to support global efforts to advance environmental sustainability. To date, however, there has been little appraisal of the use-cases or systematic orientation to vital environmental opportunities and challenges, much less of how to build the public-private collaborations and platforms that will be needed to realize these nascent opportunities.

This report focuses on the application of blockchain to address pressing environmental challenges such as climate change, biodiversity loss and water scarcity. It looks at emerging applications, including those that might be the biggest game changers in managing our global environmental commons, while assessing the potential challenges and developing recommendations to address them. Some of these applications could dramatically improve current systems and approaches, while others could completely transform the way humans interact with – and manage – our environmental stability and natural resources.

Throughout this assessment, it is emphasized that the potential for blockchain lies in its architectural ability to shift, and potentially upend, traditional economic systems – potentially transferring value from shareholders to stakeholders as distributed solutions increasingly take hold.

If harnessed in the right way, blockchain has significant potential to enable a move to cleaner and more resource-preserving decentralized solutions, unlock natural capital and empower communities. This is particularly important for the environment, where global commons and non-financial value challenges are currently so prevalent.

However, if history has taught us anything, it is that such transformative changes will not happen automatically. They will require deliberate collaboration between diverse stakeholders ranging from technology industries through to environmental policy-makers, underpinned by new platforms that can support these stakeholders to advance not just a technology application, but the systems shift that will enable it to truly take hold. It is our hope that the following overview of the opportunities, risks and suggested next steps will stimulate stakeholders to embark on an exciting new action agenda that builds blockchains for a better planet.

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Executive Summary

Background

Blockchain has the potential to transform how humans transact. It is a decentralized electronic ledger system that creates a cryptographically secure and immutable record of any transaction of value, whether it be money, goods, property, work or votes. This architecture can be harnessed to facilitate peer-to-peer payments, manage records, track physical objects and transfer value via smart contracts.

This potential to fundamentally redefine how business, governance and society operate has generated considerable hype about blockchain. Despite this hype, it remains a nascent technology with considerable challenges that need to be overcome, from user trust and adoption through to technology barriers (including interoperability and scalability), security risks, legal and regulatory challenges, and blockchain's current energy consumption.

However, as the technology matures and its application across sectors and systems grows, there is both a challenge and an opportunity to realize blockchain's potential – not just for finance or industry, but for people and the planet. This opportunity comes at a critical juncture in humanity's development. As a result of the "great acceleration" in human economic activity since the mid-20th century, which has yielded impressive improvements in human welfare, research from many Earth-system scientists suggests that life on land could now be entering a period of unprecedented environmental systems change.

Fortunately, an opportunity is also emerging to harness blockchain (and other innovations of the Fourth Industrial Revolution) to address six of today's most pressing environmental challenges that demand transformative action: climate change, natural disasters, biodiversity loss, ocean-health deterioration, air pollution and water scarcity. Many of these opportunities extend far beyond "tech for good" considerations and are connected to global economic, industrial and human systems. Blockchain provides a strong potential to unlock and monetize value that is currently embedded (but unrealized) in environmental systems, and there is a clear gap within the market. In the first quarter of 2018, for example, 412 blockchain projects raised more than $3.3 billion through initial coin offerings (ICOs).[5] Less than 1% of these were in the energy and utilities sector, representing around $100 million of investment, or around just 3% of the total investment for the quarter.

Principal findings

Our research and analysis identified more than 65 existing and emerging blockchain use cases for the environment through desk-based research and interviews with a range of stakeholders at the forefront of applying blockchain across industry, big tech, entrepreneurs, research and government.

Blockchain use-case solutions that are particularly relevant across environmental applications tend to cluster around the following cross-cutting themes: enabling the transition to cleaner and more efficient decentralized systems; peer-to-peer trading of resources or permits; supply-chain transparency and management; new financing models for environmental outcomes; and the realization of non-financial value and natural capital.

The report also identifies enormous potential to create blockchain-enabled "game changers" that have the ability to deliver transformative solutions to environmental challenges. These game changers have the potential to disrupt, or substantially optimize, the systems that are critical to addressing many environmental challenges. A high-level summary of those game changers is outlined below:

- **"See-through" supply chains:** blockchain can create undeniable (and potentially unavoidable) transparency in supply chains. Recording transactional data throughout the supply chain on a blockchain and establishing an immutable record of provenance (i.e. origin) offers the potential for full traceability of products from source to store. Providing such transparency creates an opportunity to optimize supply-and-demand management, build resilience and ultimately enable more sustainable production, logistics and consumer choice.

- **Decentralized and sustainable resource management:** blockchain can underpin a transition to decentralized utility systems at scale. Platforms could collate distributed data on resources (e.g. household-level water and energy data from smart sensors) to end the current asymmetry of information that exists between stakeholders, enabling more informed – and even decentralized – decision-making regarding system design and management of resources. This could include peer-to-peer transactions, dynamic pricing and optimal demand-supply balancing.
- **Raising the trillions – new sources of sustainable finance**: blockchain-enabled finance platforms could potentially revolutionize access to capital and unlock potential for new investors in projects that address environmental challenges – from retail-level investment in green infrastructure projects through to enabling blended finance or charitable donations for developing countries. On a broader level, there is the potential for blockchain to facilitate a system shift from shareholder to stakeholder value, and to expand traditional financial capital accounting to also capture social and environmental capital. Collectively, these changes could help raise the trillions of dollars needed to finance a shift to low-carbon and environmentally sustainable economies.
- **Incentivizing circular economies:** blockchain could fundamentally change the way in which materials and natural resources are valued and traded, incentivizing individuals, companies and governments to unlock financial value from things that are currently wasted, discarded or treated as economically invaluable. This could drive widespread behaviour change and help to realize a truly circular economy.
- **Transforming carbon (and other environmental) markets:** blockchain platforms could be harnessed to use cryptographic tokens with a tradable value to optimize existing market platforms for carbon (or other substances) and create new opportunities for carbon credit transactions.
- **Next-gen sustainability monitoring, reporting and verification:** blockchain has the potential to transform both sustainability reporting and assurance, helping companies manage, demonstrate and improve their performance, while enabling consumers and investors to make better-informed decisions. This could drive a new wave of accountability and action, as this information filters up to board-level managers and provides them with a more complete picture for managing risk and reward profiles.
- **Automatic disaster preparedness and humanitarian relief:** blockchain could underpin a new shared system for multiple parties involved in disaster preparedness and relief to improve the efficiency, effectiveness, coordination and trust of resources. An interoperable decentralized system could enable the sharing of information (e.g. individual relief activities transparent to all other parties within the distributed network) and rapid automated transactions via smart contracts. This could improve efficiencies in the immediate aftermath of disasters, which is the most critical time for limiting loss of life and other human impacts.
- **Earth-management platforms:** new blockchain-enabled geospatial platforms, which enable a range of value-based transactions, are in the early stages of exploration and could monitor, manage and enable market mechanisms that protect the global environmental commons – from life on land to ocean health. Such applications are further away in terms of technical and logistical feasibility, but they remain exciting to contemplate.

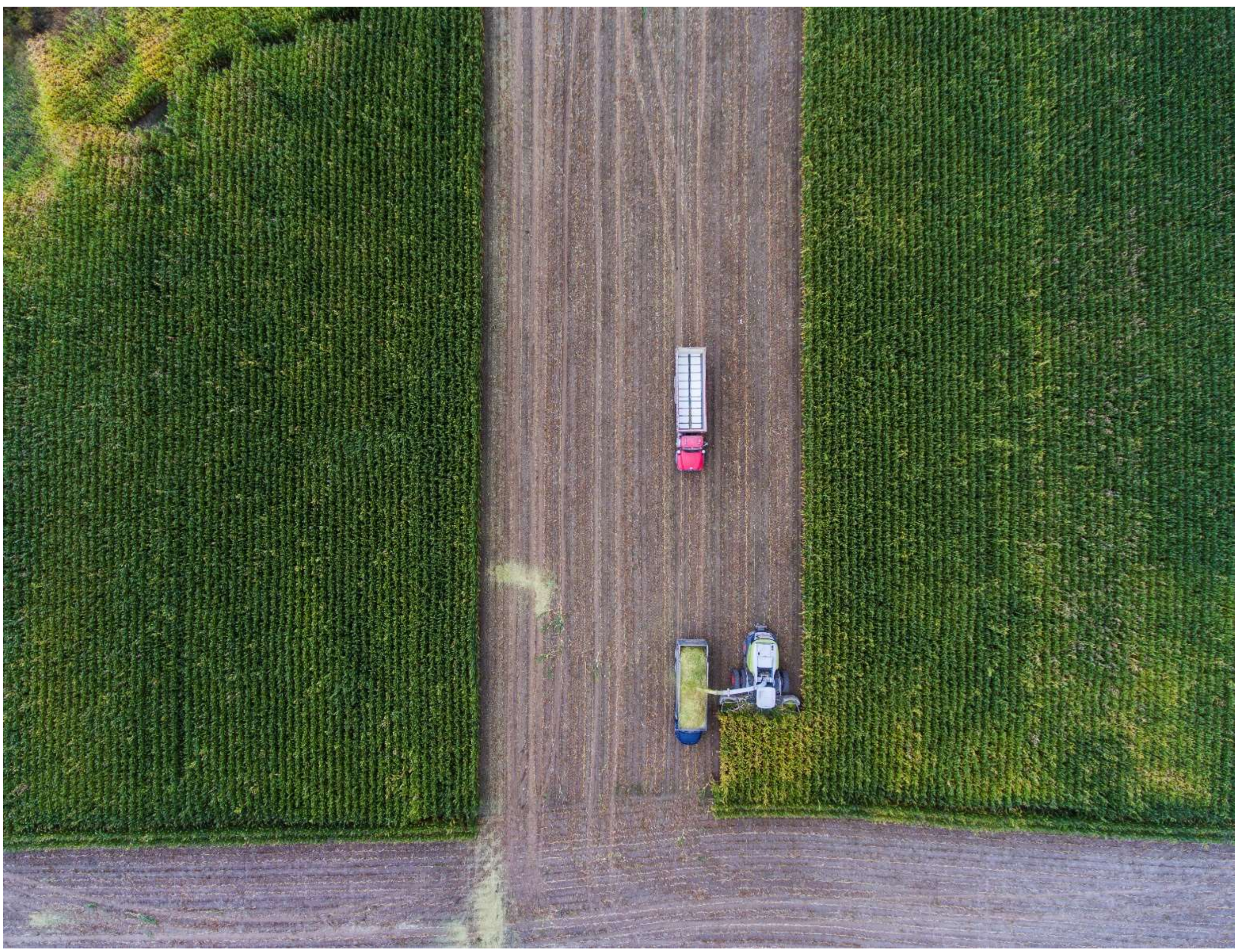
These game changers, and the more than 65 use cases identified, offer the exciting potential to build a sustainable future; however, as with many emerging technologies, there are a number of risks to manage and challenges to overcome. In broad terms, the challenges relate to blockchain's maturity as a technology, regulatory and legal challenges, stakeholders' trust in the technology, and their willingness to invest and participate in applications. Managing and overcoming these risks and challenges will require stakeholders to work together to develop solutions that are effective, holistic, relevant and deployable. Currently, such collaborative efforts are few in number, making it almost impossible for stakeholders to fully harness the potential opportunities that blockchain technology provides.

Harnessing blockchain technologies to drive sustainable and resilient growth and a new wave of value creation will require decisive action. The opportunities that blockchain offers need to be developed and governed wisely, with upfront and continual management of unintended consequences and downside risks. A variety of measures will be needed, from ensuring compliance with privacy rights, improving security and clarifying accountability in case things go wrong, through to establishing standards for minimizing energy consumption. These responsibilities are shared by all stakeholders.

Establishing new global platforms or accelerators focused on creating a “responsible blockchain ecosystem”, rather than just incubating specific projects, would be a valuable and much-needed next step. Such a platform could support stakeholders from across different sectors to develop effective blockchain solutions for environmental challenges, help ensure blockchain technology is sustainable (i.e. good for people and the planet) and play a crucial role in building out the necessary governance arrangements at industrial, state and global levels.

Finally, today’s hype surrounding blockchain can lead to the temptation to try to use blockchain to solve everything. A reasoned and structured approach is needed to help practitioners assess whether and how to deploy blockchain for delivering new environmental solutions. The following three broad principles should be the starting point for any such assessment:

- **Will blockchain solve your actual problem?** Consider whether blockchain is actually needed to solve the problem by clearly identifying what the problem is and whether distributed ledger technology is really needed to deliver your envisaged solution.
- **Can you acceptably manage the downside risks or unintended consequences?** Consider the risks and challenges posed by a blockchain-enabled solution, the technical and commercial feasibility of being able to mitigate these and the likely time frames to realize them.
- **Have you built the right ecosystem of stakeholders?** Blockchain’s value as a solution multiplies when more players participate and when stakeholders come together to cooperate on matters of industry-wide or system-level importance. New partnerships and opportunities are more likely to emerge from multidisciplinary ecosystems.



Our planet: The challenge and opportunity

The challenge

From an anthropocentric perspective, the past century (particularly the past few decades) of human existence has marked a very successful period for population and economic growth.[6]

The "great acceleration"[7] in human activity, particularly since the mid-20th century, has delivered exponential economic growth. Real output grew five-fold in the four centuries leading to 1900, before accelerating more than 20-fold in the 20th century.[8] The past 60 years and, in particular, the past 25 years, have witnessed an increased acceleration in human economic activity. The recent past is an example of markets working to their fullest extent, as technologies have driven progress and real commodity prices have fallen, despite a 20-fold increase in demand for certain resources.[9] The follow-on effects have included impressive improvements in human welfare as the number of people living on less than $1.25 a day has been cut by one-half since 1990[10] and more than 700 million people have moved into the global middle classes.[11]

Yet, from an Earth-systems perspective, the human success story is not so positive. The stress on the Earth's natural systems caused by human activity has worsened considerably in the 25 years since the 1992 Rio de Janeiro Earth Summit in Brazil.

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 past 10,000 years. During this period, they have functioned within a "Goldilocks" zone – not too hot and not too cold – for humans.[12]

However, as a result of the great acceleration in human economic activity since the mid-20th century, research from many Earth-system scientists suggests that our planetary systems could now be entering a period of unprecedented environmental systems change. This change can be observed across six critical challenge areas, with implications for the planet and human prosperity, and demands transformative action early in the 21st century, as illustrated in Figure 1.

Figure 1: Global challenge areas

Climate change

- Today's greenhouse gas levels may be the highest in 3 million years, rising to 412 parts per million in May 2018.[13]

Economic and human impact:

- Changes in precipitation, extreme storms, rising sea levels, coastal inundation and heatwaves directly affect people's security, economic well-being and health. For instance, deaths caused by extreme heat in Europe could rise to 150,000 a year by 2100.[14]

Biodiversity and conservation

- The Earth is losing its biodiversity at mass extinction rates. One in five species on Earth now faces eradication; this will rise to 50% by the end of the century unless we take urgent action.[15]

Economic and human impact:

- 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.[16] Biodiversity loss has a direct human impact – threatening energy, clean water and food supply.

Healthy oceans

- The chemistry of the oceans is changing more rapidly than at any time in perhaps 300 million years, as the water absorbs anthropogenic greenhouse gases. The resulting ocean acidification and warming are leading to unprecedented damage to fish stocks and corals.[17]

Economic and human impact:

- Some 8 million tonnes of plastic are predicted to enter the oceans each year.[18] Plastics – and the toxins they often carry – accumulate in the food chain and find their way into humans. Estimates suggest around 6,400 microplastics per year are ingested by the average European shellfish consumer.[19]

Water security

- The world's demand for water has grown by around 1% per year. By 2030, we may fall 40% short of the amount of fresh water needed to support the global economy as pollution and climate change affect the global water cycle.[20]

Economic and human impact:

- For 1.9 billion people, water scarcity is already a reality – this number is expected to rise to 3 billion by 2050.[21] Microplastic fibres were found in 83% of tap water samples around the world[22] and more than 90% of bottled water analysed.[23]

Clean air

- Around 91% of the world's people live in places that fail to meet World Health Organization (WHO) air-quality guidelines.[24]

Economic and human impact:

- Around 7 million people die annually from exposure to air pollution – one death out of every eight globally.[25]

Weather and disaster resilience

- In 2017, the world suffered 710 geophysical, meteorological, hydrological and climatological "natural-loss events" – almost triple the number it suffered in 1980.[26]

Economic and human impact:

- These events caused approximately $330 billion in damages, less than half of which was covered by insurance.[27] In parallel, 23 million people were displaced.[28]

Over the coming decades, these six critical challenges are set to intensify as global trends are expected to put an increasing strain on finite resources. The current world population of around 7 billion is expected to grow to nearly 10 billion by 2050. As the world becomes more populous and the global middle class grows in size, it will increase the demand for energy, transport, food and water. Under current approaches, as our consumption of resources continues to rise, so do the levels of waste, plastic and pollution. To put this in perspective, 8.3 billion tonnes of plastic have been created in the past century, more than 70% of which is now in waste streams. Alongside this, societies are under growing social and economic strain from mounting inequality, youth unemployment, the threat of automation and geopolitical volatility. Many of these issues are exacerbated by environmental deterioration.

While we have seen a progressive increase in environmental interventions over the past four decades, the breadth and depth of environmental challenges and the pace with which they are evolving demonstrates the need for governments, regulators and businesses to adapt more quickly than before. Business as usual is clearly not enough, and the evidence shows that progress made over the past four decades has been insufficient for the scale of the challenge.

The opportunity

While these challenges are urgent and extraordinary, they also coincide with an era of unprecedented innovation, technical change and global connectivity – the Fourth Industrial Revolution.

This industrial revolution, unlike previous ones, is underpinned by the established digital economy and is based on rapid advances in technologies such as blockchain, artificial intelligence, the Internet of Things, robotics, autonomous vehicles, biotechnology, nanotechnology and nascent quantum computing among others. It is also characterized by the way in which the combination of these technologies increasingly merges the digital, physical and biological realms, and collectively increases the speed, intelligence and efficiency of business and societal processes.

The Fourth Industrial Revolution generates opportunities for global growth and value creation that far outstrip the advancements of the past century. Left unguided, these advancements have the potential to accelerate the environment's degradation. However, they also create an opportunity for governments, regulators and companies to make the Fourth Industrial Revolution the first sustainable industrial revolution by harnessing these rapidly evolving technologies to overcome the world's most pressing environmental challenges.

Blockchain for the Earth

The Fourth Industrial Revolution includes a new phase of blockchain-enabled innovation. The computational architecture of blockchain technology creates a wide range of potential uses. For example, by providing an immutable, distributed ledger, it can help to facilitate peer-to-peer payments, manage records, track physical objects and transfer value via smart contracts, all without a third party or manual reconciliation.

During 2017 and 2018, blockchain has received considerable hype regarding its potential to create wide-reaching impact, with proponents projecting that it could account for as much as 10% of global GDP by 2025. There has also been considerable scepticism with regard to its performance and scalability that has thus far kept crypto-networks from seriously disrupting centralized systems. During the next few years, the focus will likely be on fixing these technical limitations and addressing regulatory and legal challenges. As the technology matures, there is both a challenge and an opportunity to realize blockchain's potential – not just for finance or industry, but for people and the planet.

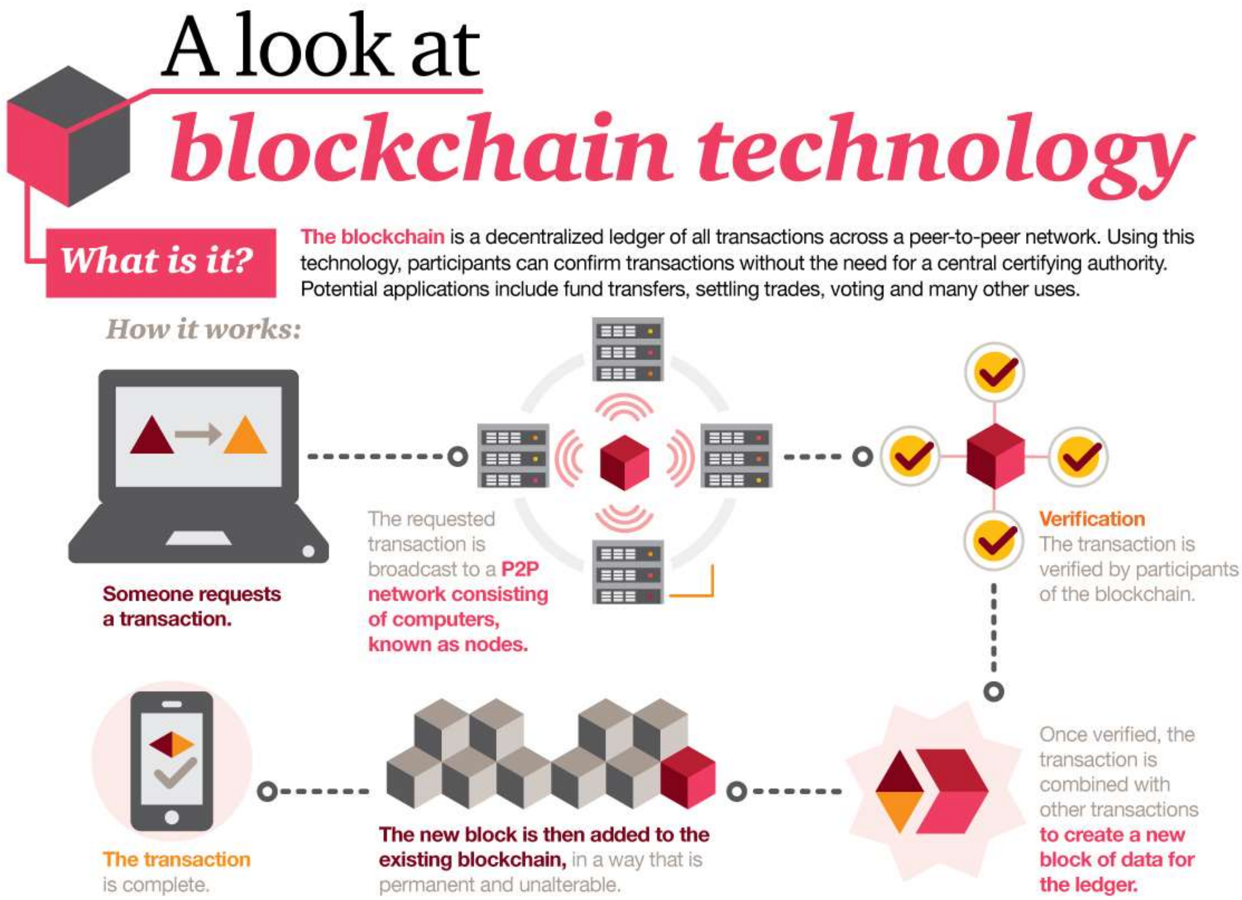
This analysis explores the opportunity to harness blockchain to address environmental challenges, including climate change, loss of biosphere integrity and water scarcity. Potential and emerging use-cases and game-changing solutions are explored. Emerging opportunities include the management of supply chains and finite resources, enabling the financing of environmental solutions and incentivizing behaviour change.

The challenge is to unlock the potential in a way that ensures inclusion, safety, interoperability and scale. Whether or not the technology succeeds will not be exclusively determined by its technical performance, scalability and resilience. It will also depend on the level of responsible development and adoption, and will require fit-for-purpose and supportive new regulatory and legal systems, investment landscapes and societal understanding and acceptance.

The building blocks: Overview of blockchain and its maturity

Blockchain basics

Figure 2: A look at blockchain technology



Key current features

Cryptocurrency

A cryptocurrency is a digital currency that uses strong cryptography to secure financial transactions, control the creation of additional units, and verify the transfer of assets. The first blockchain was developed in the financial sector to serve as the basis for the cryptocurrency "bitcoin", which continues to be the blockchain application best known to the general public.

Smart contracts

Smart contracts use a digital protocol to automatically execute predefined processes of a transaction without requiring the involvement of a third party or intermediary. They were initially built upon the Ethereum protocol and operate on the basis of individually defined rules (e.g. quantity, quality or price specifications) that enable an autonomous matching of distributed providers and prospective customers.

Benefits

- Enables decentralized systems incl. peer-to-peer transactions
- Increased transparency, tracking and traceability
- Immutable, reliable and shareable ledger of transactions
- Reduced transaction costs via disintermediation and automation
- Promotes dynamic pricing
- Access to markets for investors and issuers, incl. non-traditional assets
- Enables effective monitoring, auditing and compliance

Challenges

- Adoption challenges
- Technology barriers
- Security risks
- Legal and regulatory challenges
- Interoperability risks
- Energy consumption challenges

Source: PwC

Blockchain is a decentralized (distributed) electronic ledger system that records any transaction of value whether it be money, goods, property, work or votes.[29] It is also an interlinked and continuously expanding list of records stored securely across a peer-to-peer network.[30] Every participant with access can simultaneously view information with no single point of failure, creating trust in the system as a whole.

Each "block" is uniquely connected to the previous blocks by including the hash[31] of the previous block in the new block. Digital signatures are then used to authenticate transactions. This structure means that making a change without disturbing the subsequent records in the chain is extremely difficult. These characteristics make blockchain cryptographically secure and currently tamper-proof.

Verification of transactions is achieved by participants confirming changes with one another, replacing the need for a third party to authorize transactions. Decentralized consensus makes blockchain platforms immutable, and updatable only via consensus or agreement among peers. This design is meant to protect against domination of the network by any single computer or group of computers.

Blockchains can be public, private (permissioned) or hybrid systems. Unlike public blockchains, whereby transactions can be validated by anyone and there is no access control – private blockchain participants or validators must be authorized by the owners of the blockchain. Between the two there are hybrid systems, combining both private- and public-ledger characteristics.[32]

Why now?

Distributed computing and cryptography have both existed for decades. However, in 2009 these ideas came together in the form of Bitcoin: a cryptocurrency network. Though initially slow to take hold, more recently there has been a proliferation of its use and a rapid increase in the number of transactions. As the world became enamoured with Bitcoin, both large corporations (first financial institutions, then others) and smaller-scale technology entrepreneurs saw a bigger picture. The underlying technology behind Bitcoin had the power to cut intermediary and reconciliation costs and revolutionize manual, frequently disjointed, opaque processes to increase their efficiency. Thus, broader ideas and conceptual applications for blockchain technology emerged.

For example, the creation of Ethereum in 2015 (now a $25 billion crypto-network) showed that blockchain was more than just a niche technology for the financial sector, but also offered a new, decentralized, trusted and transparent platform that could benefit a wider range of industries and issues, with developers naturally seeking out areas where it could add the most value.

As the volume of coders proficient in blockchain has increased, start-ups and established corporations alike have begun to invest in tools, data, people and blockchain-enabled innovations. ICOs have also emerged as a new crypto-based alternative to classic early-stage capital/debt finance, creating opportunities to quickly fund new blockchain technology ventures. This has encouraged more investors, speculators and entrepreneurs to take an interest in this emerging and potentially powerful technology.

At the same time, a number of converging global trends have helped to create an environment conducive to the proliferation of blockchain. Increasingly, digitalization and connectivity of the global economy, along with the emergence of powerful global tech firms, has meant that corporations have become increasingly open to adopting blockchain and other emerging technologies of the Fourth Industrial Revolution. Developments in computer processing power and networked computer systems have facilitated advances in blockchain programs, while the domination of smartphones has made digital wallets possible and increasingly relevant. Alongside this, there has been a proliferation of IoT and AI applications that can automate big-data collection and processing for use in blockchain platforms.

Taken together, these advances in technology and an emerging global enabling environment have created a platform from which many blockchain applications are now being launched.

Blockchain capabilities: now and in the future

It is worth noting that the technology itself is still very new, and there is a considerable way to go to build trust among businesses, investors and regulators in relation to blockchain applications.

However, blockchain's potential – and at least some of the associated hype – stems from a combination of its current capability and the anticipated technology development roadmap, which suggest that as the technology matures it could become a foundational technology like the internet and could dramatically improve operating efficiencies in some sectors while completely disrupting others. Two of today's most prominent blockchain applications – cryptocurrencies and smart contracts – illustrate this potential.

Cryptocurrencies are designed to be used as an alternative to real currencies and to create new token economies that, among other things, could capture and monetize currently unrealized economic value, while smart contracts use a digital protocol to automatically execute predefined processes of a transaction without requiring the involvement of a third party or intermediary.

The next few years of blockchain will focus on fixing the most severe technical limitations of blockchain networks' performance and scalability, as these are limitations that currently keep them from challenging centralized incumbents. In particular, these limitations relate to blockchain's distributed verification protocols.

To avoid the use of an intermediary, blockchain applications are characterized by a distributed verification process, which is designed to achieve consensus on the content of the distributed ledger. The following two mechanisms are most commonly used for verification of a transaction to establish consensus:

- **Proof of work (PoW):** Each block is verified through a process called "mining" before information is stored. The data contained in each block is verified using algorithms that attach a unique hash to each block based on the information stored in it. Users continuously verify the hashes of transactions through the mining process in order to update the current status of the blockchain assets. Doing so requires an enormous number of random guesses, making it a costly and energy-intensive process – one that also faces speed constraints as the network grows. Early blockchains such as Bitcoin use PoW verification.
- **Proof of stake (PoS) –** PoS simplifies the mining process. Instead of mining, users can validate and make changes to the blockchain on the basis of their existing share ("stake") in the currency. This approach reduces the complexity of the decentralized verification process and can thus deliver large savings on energy and operating costs. Increasingly, emerging blockchains such as Ethereum, NEO and WAVES use PoS verification.

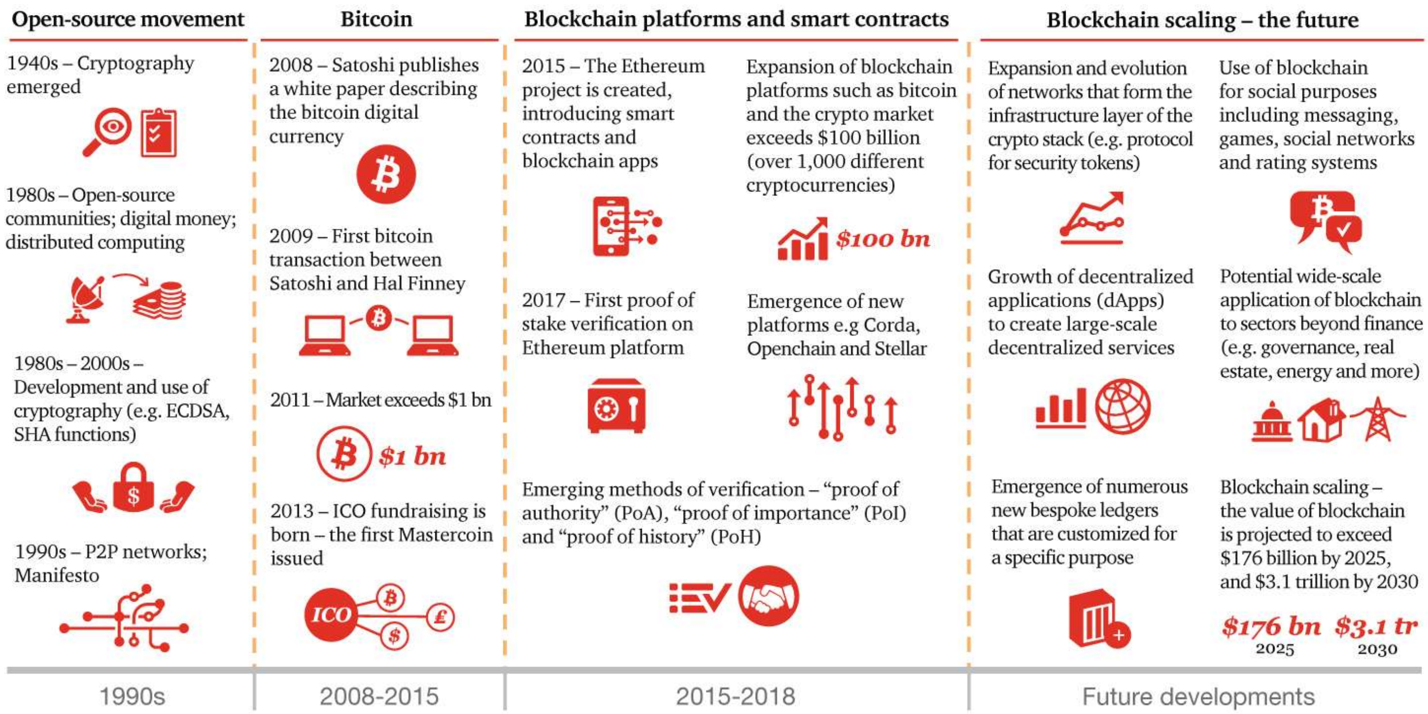
To date, PoW has been the most frequently used verification method in conjunction with blockchain technology. In light of concerns regarding cost, energy intensity and scalability, however, emerging blockchain applications rely increasingly on PoS and other less cost- and energy-intensive verification methods. Recent and emerging verification methods include (but are not limited to) "proof of authority" (PoA), "proof of importance" (PoI) and "proof of history" (PoH), which are also deemed to be less cost-, energy- and time-intensive (see Glossary for terms). Second-layer "proof of stake" solutions currently being developed for the Ethereum platform, such as Casper, Plasma and Sharding, should address the fundamental scalability challenges of Ethereum and pave the way for more innovative and scalable protocols.

Once the networks that form the infrastructure layer of the cryptostack are built, technologists will increasingly turn their energy to building decentralized applications (dApps) on top of this infrastructure. We are also likely to see the emergence of numerous bespoke ledgers customized for specific purposes. In parallel, there will need to be a focus on developing fit-for-purpose regulation, and on industry and multistakeholder efforts to experiment, adopt and apply the technology, building trust when doing so. The speed at which such technical developments could unfold makes it crucial for the notion of responsible blockchain to be rapidly adopted by all stakeholders, in particular the burgeoning developer community.

Like any new and evolving technology, further advances in blockchain are difficult to predict accurately as the technology (and its potential) are evolving so fast that it can be hard to know how much of the hype will be realized and, in turn, how exactly the broader enabling market will mature. How far and how fast blockchain evolves will be somewhat a function of how quickly (and successfully) technical, regulatory, scalability and other challenges – including trust – can be overcome (see below). One area to watch will be the financial and social incentives created as these will likely determine the aspects on which developers focus and where investment flows. We can also expect the most transformational blockchain use-cases to emerge where collaborative and multistakeholder ecosystems are built to tackle matters of industry-wide or society-wide importance – such as decentralized energy platforms.

Looking further afield, expected advances in AI, distributed computing and quantum computing will likely support – and potentially accelerate – blockchain's technological evolution. If it truly lives up to its promise, this new global computational architecture could rewire commerce and transform how society operates, becoming one of the most significant innovations since the creation of the internet. The opportunity to harness this innovation to help tackle environmental challenges is equally significant.

Figure 3: Timeline of blockchain developments

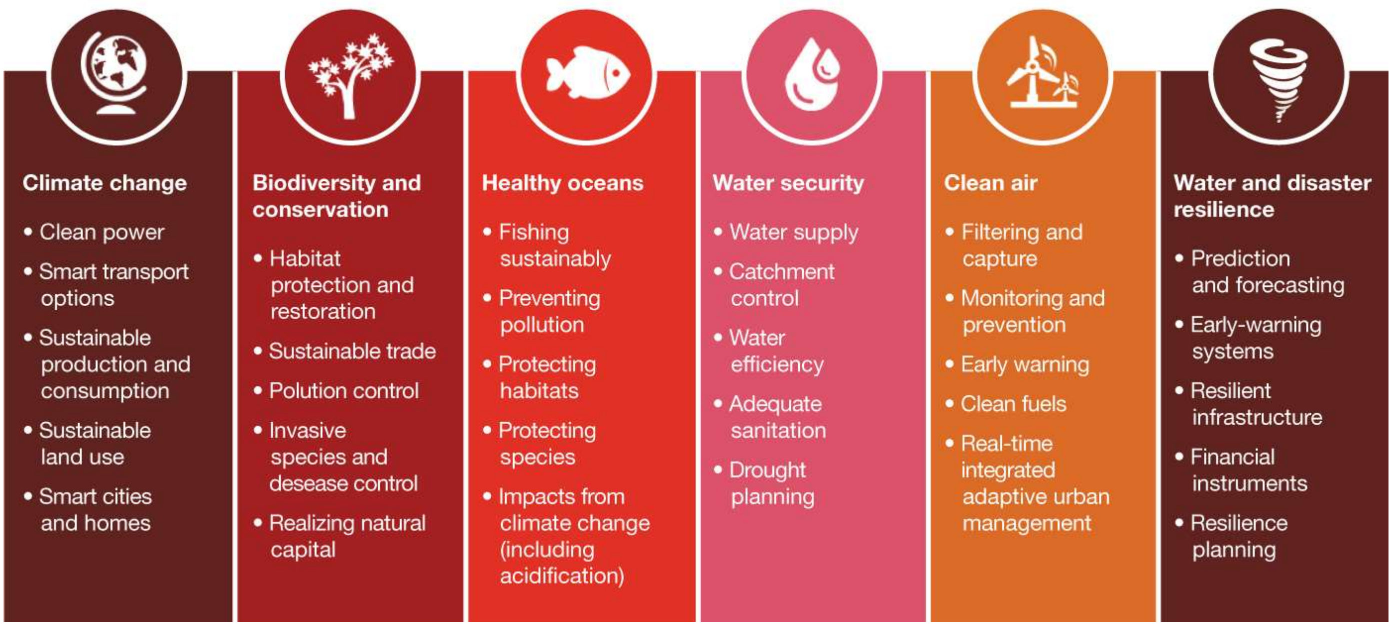


Source: PwC research

The blockchain opportunity for our environment

While blockchain has the potential to become a powerful foundational technology used across different sectors to tackle a wide range of challenges and opportunities, if it is to be truly transformative for our global environment, it will need to be deployed in the right areas. Figure 4 highlights six of the world's most pressing environmental challenges and the priority action areas to successfully address them.

Figure 4: Priority action areas for addressing Earth challenge areas



Source: PwC research

In meeting these challenges, there is wide scope for innovation and investment. There is potential for blockchain to provide solutions in and of itself and also to facilitate solutions that involve other Fourth Industrial Revolution technologies. Indeed, more than 65 existing and emerging blockchain use cases for the environment were identified through desk-based research and interviews with a range of stakeholders from the industrial, technological and entrepreneurial sectors, in addition to research associations and governments.

Figure 5 provides a glimpse of such blockchain applications by environmental challenge area. The snapshots are not intended to be exhaustive, but to provide an initial overview, represent the most prominent innovations and stimulate a more concerted action agenda.

These snapshots show that each environmental challenge area stands to benefit from the use and deployment of blockchain, and that the majority of solutions operate by transforming an underlying economic, industrial or governance system. Many of the use-cases also represent opportunities to unlock and monetize (or tokenize) economic value that is currently embedded within environmental and natural resource systems, but which has been largely unrealized to date. Examples include opportunities to build an inclusive bio-economy, capture the value of intact forests and create new markets for trading natural resources.

Currently, the majority of use-cases identified are in the concept or pilot phase, with only a handful having been fully developed.

Climate change and biodiversity were the challenge areas where most use-cases were identified, with fewer developed in the areas of water resource management, ocean management and clean air so far. Recent investment figures highlight the largely untapped nature of the opportunity. In the first quarter of 2018, for example, 412 blockchain projects raised more than $3.3 billion through ICOs.[33] However, less than 1% of these were in the energy and utilities sector, representing around $100 million of investment, or around 3% of the total investment for the quarter.

The more than 65 use case solutions identified as being particularly relevant across environmental applications tend to cluster around the following cross-cutting themes:

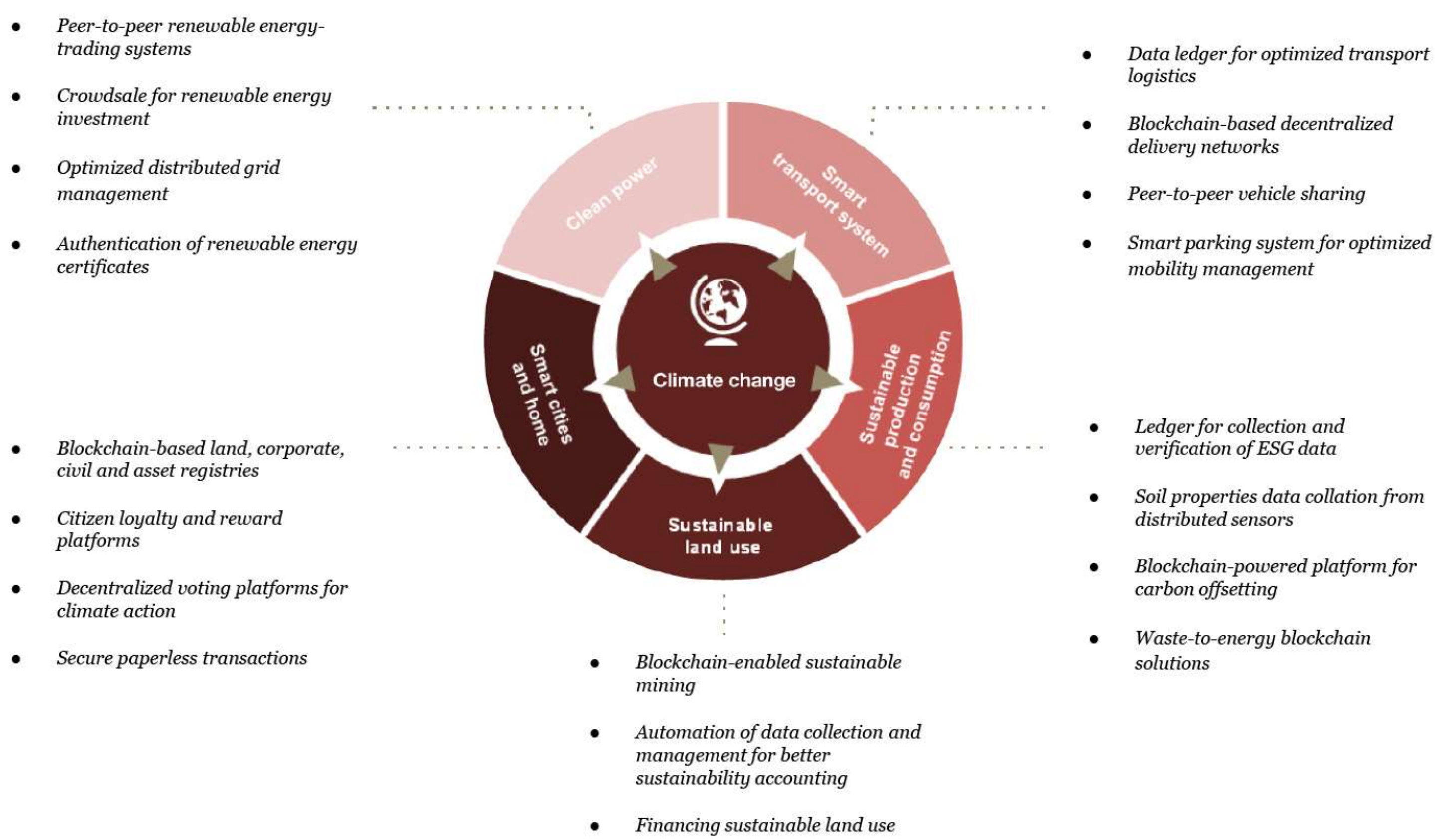
- Enabling decentralized systems
- Peer-to-peer trading of natural resources or permits
- Supply chain monitoring and origin tracking
- New financing models, including democratizing investment
- Realization of non-financial value, including natural capital

The challenge for innovators, investors and governments is to identify and scale these pioneering innovations both for people and the planet – while also making sustainability considerations central to wider blockchain development and use.

While blockchain-based solutions hold great promise, there is also a lot of hype associated with the technology. On its own, it is not necessarily transformational for the environment. However, the potential of blockchain to help solve environmental challenges can be amplified exponentially when it is combined with other emerging Fourth Industrial Revolution technologies such as AI, IoT, drones, 3D printing and biotechnologies. When it is applied this way – as a “cocktail mixer” for other emerging technologies – blockchain starts to become a truly game-changing technology. Some of those game-changing examples, drawing on emerging use-cases in Figure 5 below, are set out in the next section, “Blockchain game changers for the Earth”.

Figure 5: Blockchain applications by challenge area

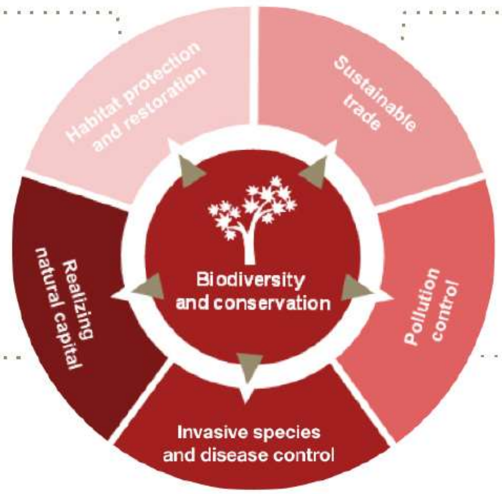
Climate change



Biodiversity and conservation

- *Cryptocurrency for investment in habitat restoration and species conservation*
- *Tracking geographic reach and movement of endangered species*
- *Incentivization for farmers to protect habitats*

- *Transparent monitoring of supply-chain transactions*
- *Real-time traceability of supply chains*



- *Timber and other natural resources provenance tracking*
- *A decentralized natural asset exchange platform*

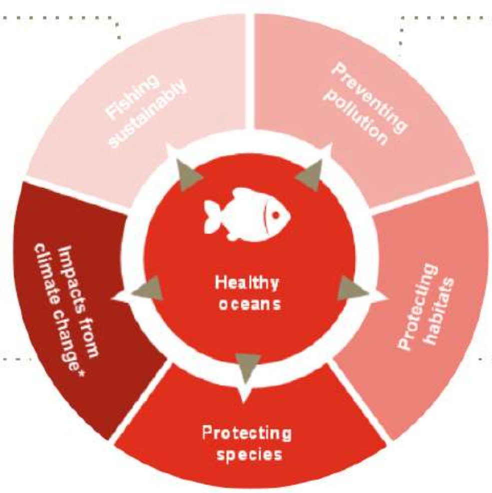
- *Recording of pesticide use on agricultural land*
- *Incentivized system for responsible waste management*

- *Digital data platform for species tracking and disease control*

Healthy oceans

- *Tracking fish provenance*
- *Monitoring of illegal fishing activities*

- *Incentivized ocean plastic recycling initiatives*
- *Transparent ledger for faster, safer and more efficient shipping*



- *Real-time monitoring of ocean temperature and pH*
- *Incentivized collection of data on ocean conditions*
- *Incentivized investments in ocean conservation*

- *Decentralized and open-source ledger of ocean data*

- *Fundraising for marine wildlife conservation*

Water security

- *Water monitoring and management*
- *Micropayments for water meter donations*

- *Decentralized, catchment-based approach to improving water quality*
- *Water quality control in catchment areas*

- *Precipitation intensity monitoring and forecasting*
- *Automated crop insurance for drought periods*

- *Blockchain-enabled peer-to-peer trading of excess water resources*
- *Cryptocurrency-enabled smart meters*

- *Asset-backed token system for clean, accessible drinking water*
- *Hyperlocal water data for monitoring water quality*
- *Efficient water treatment systems*

Clean air

- *Air pollutant data collation from distributed sources*
- *Automated activation of air-filtration devices*

- *Local and real-time monitoring of particulates and NO2*
- *Intelligent methane monitoring systems*

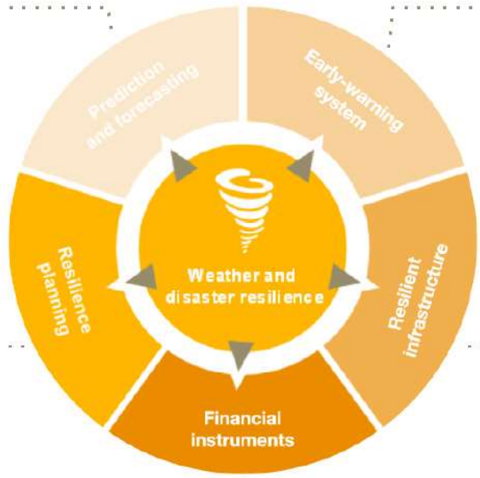
- *Cryptocurrency payments for EV public charging*
- *Enabling safe and realiable AV implementation*

- *Automated air-quality monitoring system*
- *Early detection of toxic chemical leaks*

Weather and disaster resilience

- *Extreme weather impact analysis*
- *Ledger to identify, verify and transact weather data*

- *Real-time monitoring of natural hazards*
- *Decentralized weather sensors generating automated alerts*



- *Enhanced emergency disaster response*

- *Automatic rerouting of power to prevent blackouts*
- *Decentralized mini-grids improving disaster resilience*

- *Disaster recovery funding*
- *Decentralized disaster insurance platforms*
- *Management of transactions in response to extreme weather event*
- *Crowdsale for adaptation investments*

Source: PwC research

Blockchain game changers for the Earth

In addition to enhancing current efforts to address environmental issues, there is enormous potential to create blockchain-enabled "game changers" in which the application of blockchain, often in combination with other Fourth Industrial Revolution technologies, has the potential to deliver transformative or disruptive solutions.

The following set of potential game changers are defined by five important features:

1. **Transformational impact** (i.e. it could completely disrupt or alter current approaches)
2. **Adoption potential** (i.e. the potential population size is significant)
3. **Centrality of blockchain to the solution** (i.e. blockchain is a vital cog in the solution)
4. **Systems impact** (i.e. the game changer could really shift the dial across human systems)
5. **Realizable enabling environment, including political and social dynamics** (i.e. the enabling environment can be identified and supported)

The eight most significant game changers are listed below. Some of these are cross-cutting and more overarching in nature (but clearly have significant ramifications for environmental challenges), while others focus more specifically on environmental challenges. Although some of these game changers could improve the efficiency of existing markets, others could drive transformational shifts in how we operate and how we tackle environmental challenges.

1. 'See through' supply chains

Transactional data throughout the supply chain can be recorded through the blockchain and an immutable record of provenance (i.e. origin) can be created, offering the potential for full traceability of products from source to store. Providing such transparency creates an opportunity to optimize supply-and-demand management, build resilience and ultimately enable more sustainable production, logistics and consumption. There are a number of potential applications, some of which are more advanced and specifically address environmental challenges.

Corporations are facing increasing regulatory, reputational, investor and consumer pressure to address supply chain risks, such as corruption, human rights violations, modern slavery, gender-based violence, water security and environmental degradation. An increasing number of companies are responding with bold public commitments – from 100% renewable energy use[34] to zero deforestation,[35] conflict-free minerals or 100% recycled material[36] pledges. However, global supply chains are often complex and opaque, and companies frequently struggle to implement their commitments or showcase their achievements in the absence of better visibility into their supply chains. Such provenance, traceability and transparency of data across supply chains is also critical to business management in a broader sense – from improving enterprise-risk management practices to enabling corporate disclosure and reporting.

Blockchain-based solutions are providing, for the first time, full transparency and traceability within the supply chain. This can build confidence in legitimate operations, expose illegal or unethical market trading or activities, mitigate quality or safety problems, reduce administrative costs, enable greater access to finance, improve monitoring, verification and reporting, and potentially help avoid litigation. As these solutions become more mainstream, they will likely push companies to be aware of their actions, and enable them to clearly demonstrate responsible and ethical operations in a cost- and time-efficient way. Better corporate data will also enable investors and asset managers to implement responsible investing practices with improved effect.

Solutions that harness blockchain for supply-chain management are some of the more advanced applications currently observed that address environmental challenges.

For example, in agriculture, blockchain has been used, thanks to its ability to provide a verifiable record of possession and transaction, to manage and authenticate harvesting of resources to ensure sustainable practices. The Instituto BVRio has developed an online trading platform it has termed a "Responsible Timber Exchange" to increase efficiency, transparency and reduce fraud and corruption in timber trading.[37]

In 2016, Provenance, a UK-based start-up, worked with the International Pole and Line Association (IPLA) to pilot a public blockchain tuna-tracing system from Indonesia to consumers in the UK.[38] Similarly, Carrefour Supermarkets have recently introduced an application where customers can scan products to receive information on a product's source and production processes. Ventures such as FishCoin are developing a utility token tradable for mobile phone top-up minutes in an attempt to incentivize fishers to provide information on their catch. The data captured is then transferred down the chain of custody until it reaches consumers. Such data could also be invaluable for governments seeking to better manage global fish stocks.[39]

From a consumer angle, the complexity of supply chains means that it is difficult for consumers to know how their consumption habits and purchasing decisions are affecting the environment, or the associated working and living conditions along the supply chain. Using blockchain tools to enable retailers and consumers to transparently track products from source to shop floor will enable more informed purchasing decisions.

Current barriers to scaling blockchain applications for supply-chain traceability and management include: the interoperability of blockchain solutions with existing systems for supply-chain management; the lack of supply-chain standards in place for blockchain solutions or providers; the transactional capacity of blockchains versus the capacity that big data from supply chains will require; and the regulatory implications regarding data security and privacy among participants.

An additional challenge is ensuring the reliability of information entered on the blockchain – e.g. while blockchain applications can track fish all the way from the boat to the plate, they cannot guarantee they were caught how and where the data claims. Other technologies, such as satellite monitoring and handheld DNA sequencers, could potentially help overcome this concern.

Looking into the future, blockchain has the potential to connect all stakeholders in a global supply chain – from workers in factories through to logistics companies, retailers, consumers, investors, NGOs and regulators – under one platform. A platform that provides the data, traceability, transparency and control or compliance mechanism that the given user needs would be a truly transformational proposition for workers in the informal economy and consumers alike.

Spotlight on illegal fishing

There was explosive growth in the harvest of fish from the ocean in the second half of the 20th century, as large industrial ships ventured out from local waters to reach every corner of the sea, trailing miles of hooks or nets large enough to catch Boeing 747s. As a result, two-thirds of the world's fish stocks today are overexploited.[40] The cost of mismanagement is high. A recent studsssy found that reforming management of the world's fisheries could increase the total annual catch by 16 million tonnes and increase annual profits by $53 billion, while improving the health of ocean ecosystems.[41]

One important challenge facing the industry is illegal, unreported and unregulated (IUU) fishing. The Food and Agriculture Organization of the United Nations (FAO) estimates that approximately 20% of the global fish catch is IUU – robbing governments and legitimate fishers of up to $23 billion per year.[42] The appetite for tackling this issue is clearly growing, with a number of related initiatives emerging in recent years. These include the Tuna 2020 Traceability Declaration[43] and the Global Dialogue on Seafood Traceability.[44]

Global markets could play a vital role in creating incentives for better management by offering the prospect of better prices and better market access for fish that come from well-managed fisheries. The potential of blockchain to help unlock this opportunity has caught the attention of members of the global fishing industry, global retailers and the Friends of Ocean Action[45] network, which is convened by the United Nations Secretary-General's Envoy for the Ocean, Peter Thomson, and Sweden's Deputy Prime Minister, Isabella Lövin, and is being explored for its capability, along with other technologies, to enable the eradication of IUU fishing.

Blockchain-enabled smart contracts could, for example, potentially underpin innovative tenure arrangements that give specific resource rights to communities or fishers. Additionally, blockchain could be used to track a fish from "bait to plate", providing a transparent view of the fish's origin. This could be complemented by DNA barcoding,[46] which allows the rapid identification of seafood in trade by matching fish products to a standardized genetic library for all fish species.

2. Decentralized and sustainable resource management

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

Decentralized energy grids

Decentralized energy grids, linked to the emergence of renewables and distributed generation sources around the world, are a rapidly emerging phenomenon. Decentralized energy grids have the potential to cut costs at the same time as increasing energy efficiency, improving reliability and supporting renewable energy integration. Coordination issues across these grids, however, remain largely unresolved. Blockchain can provide the solution to these issues, using smart contracts to optimize coordination, enabling genuinely local markets for energy trading. For example, installation of blockchain software with integrated smart contracts, coupled with smart-meter technology, allows for traceability and verification of energy sources, efficient peer-to-peer trading, better balancing and optimization of energy load and demand.

Peer-to-peer trading also has the potential to support and bolster renewables uptake as well as minimizing the need for energy companies, energy traders and payment providers, and reducing energy transportation losses. Furthermore, transactions can be securely and automatically recorded, with smart contracts on a blockchain establishing a transparent process that users can trust, but with better protection against cyber-attacks and without revealing personal information.

A network of companies using these types of solutions has emerged, though most are currently at trial stage. LO3 Energy and Siemens Digital Grid, for example, have launched the Brooklyn Microgrid project,[47] an early example of an open-source and scalable blockchain platform for the energy sector. “Prosumers” (consumers involved in the design, manufacture or development of a product or service), generating their own solar energy from rooftop panels, have been autonomously trading in near-real time with customers (neighbours) in the local Brooklyn market in New York.

Decentralized grids additionally have the capability to build local energy resilience: for instance, through rerouting power in response to a natural disaster, or in areas around the world where energy scarcity is prevalent. The Brooklyn Microgrid, for example, has a built-in microgrid control system, enabling redirection of electricity towards hospitals and community centres.

Looking further ahead, the global transition to electric mobility could be integrated into decentralized energy systems, further adding to energy-system storage and demand-supply balancing. BlockCharge by RWE and Slock.it are developing a mobile phone app, which links to a blockchain-based network that allows electric vehicle (EV) owners to charge their car via any charging station network and to be billed for the energy consumed.[48] The EVs interact automatically with the stations, and the electricity payment process is autonomous. This type of charging information, for regions and in aggregate, can help increase the management and optimization of decentralized grid solutions.

Decentralized water

Blockchain, combined with other Fourth Industrial Revolution technologies, could enable a step-change in the optimization of distributed water management. Real-time transparent data on water quality and quantity can inform conservation, dynamic pricing and trading, and spot illegal extraction or water tampering.

Blockchain could become a core part of the solution to enable “off-grid” water resources, analogous to decentralized energy systems.

Household smart meters can produce large volumes of data that can be used to predict water flows, spot inconsistencies and check leaks. Blockchain technology could also support peer-to-peer trading of water rights in a given basin, allowing water users willing to share their excess resources to become “prosumers” without relying on a centralized authority. The next stage will be to combine blockchain with machine learning and the internet of things to create a truly decentralized water system where local resources and closed-loop water-recycling gain value.

Realizing fully decentralized utility solutions will require sufficient regulation to assure the security and integrity of the software, ownership and control of intellectual property rights and the transferring and trading of resources, which, in some instances, will be virtual. These are surmountable challenges and the reward is the critical transition of utility infrastructure and markets to a decentralized, decarbonized and more water-secure future.

Spotlight on new energy management platforms

The transition to low-carbon energy systems will be critical in enabling governments to meet their climate commitments as part of the 2015 Paris Agreement on climate change. Scaling up the amount of renewable energy generated in the global energy mix is a central part of this transition. However, integrating high percentages of renewable energy such as solar and wind into traditional energy grids can present challenges to their stability and predictability. This is largely because renewable energy can be intermittent and is often generated from smaller-scale and less centralized sources than traditional fossil-fuel generators. To facilitate the generation and distribution of renewable energy at the scale needed, a range of transactive energy technologies enabling electricity storage, energy trading, demand forecasting and management, will need to be integrated into new, intelligent “smart grids”. Blockchain offers exciting potential to help knit such technologies and grids together.

To help progress these solutions, Grid Singularity and the Rocky Mountain Institute founded the Energy Web Foundation (EWF),[49] with an ecosystem of large utility, information and communication technology (ICT), energy and blockchain partners, including those bringing blockchain-based energy trading to real-world markets. The foundation is a global open-source, scalable blockchain platform designed specifically for the energy sector. It is currently in beta release and allows companies to develop and test applications to support, for example, micropayment channels, data analysis and benchmarking, certificates of origin, smart and microgrid management, renewable energy procurement and trading, electric-vehicle charging and demand response. Platform innovations include a more energy-efficient, decentralized proof of authority (PoA) protocol, a secret transaction feature to encrypt smart contracts and protect personal data, and a light-client version for small IoT devices to overcome potential platform-scaling issues.

As government-mandated targets for renewable energy supply and corporate commitments for sourcing renewable energy[50] increase, there is also a growing need to verify purchases of such “green” electricity. In electricity grids that draw from both renewable and non-renewable energy sources, electrons from renewables are indistinguishable from electrons generated from fossil fuels. Because of this, a secondary market can exist to represent the environmental and social benefits of the electricity purchases through Certificates of Origin (also termed Renewable Energy Credits or Guarantees of Origin). However, the system for buying such certificates is often a complex process, with many organizations acting as intermediaries, which adds a time, labour and cost burden to the process, and can breed a lack of trust as to whether they were accurately counted and traded. Blockchain’s ability to enable verification, traceability and transparency could significantly streamline this complex process and introduce confidence into the market. It could also reduce the barriers to entry for smaller organizations, encouraging further participation in markets for Certificates of Origin and helping to grow demand for renewable electricity.

3. Raising the trillions: new sources of sustainable finance

The UN estimates that there is a funding gap of $5 to $7 trillion per year to meet the SDGs, with an investment gap in developing countries of about $2.5 trillion.[51] *Employing blockchain-enabled finance platforms could potentially revolutionize access to capital and unlock potential for new investors in projects that address environmental challenges – from retail-level investment in green infrastructure projects through to charitable donations for developing countries.*

Blockchain-enabled platforms could be employed to unlock access to capital. Its ability to seamlessly manage complex financing environments means it can integrate a wide number of stakeholders, making it feasible for projects and ventures to crowdsource funds from a large number of diverse investors rather than just several large investors. Regardless of the number of investors, the decentralized framework could also significantly increase efficiency and lower transaction costs, both formal and informal.

The “tokenization” of financial investments opens up this opportunity for a wider group of stakeholders to invest. Investors with larger amounts of capital would share the same automated process as investors with very small amounts of capital; therefore, access and entry requirements are democratized. This will remove the need for third parties and could enable projects that attempt to tackle environmental challenges to access capital quickly, without being delayed by the red tape that is often a part of doing business with big institutions.

Early applications have emerged. The Sun Exchange launched a blockchain-based platform for crowdselling solar assets, connecting people who want to invest in solar with those who want access to it. This enables financing of solar projects in sub-Saharan Africa, where high upfront costs and political barriers can prevent financing from traditional investment-capital sources, which inhibits widespread deployment. In addition, the decentralized platform facilitates cross-border investments and repayments (avoiding exchange fees associated with national currency). A further example is the Clean Water Coin, which uses a blockchain platform to quickly and efficiently raise funds for clean-water projects worldwide.[52] Other nascent projects are looking at tokenizing carbon credits (e.g. Poseidon), while the Natural Asset Exchange blockchain platform and its Earth Token cryptocurrency aims to create a Natural Asset Marketplace that connects certified producers of natural capital assets with consumers of these assets.

Looking ahead, blockchain could be a real game changer for "blended finance" investment in projects seeking to deliver the UN's Sustainable Development Goals. A platform could efficiently facilitate the complexity of such transactions where different types of funding, traditional and non-traditional assets, and multiple stakeholders with multiple requirements are involved.[53]

The overall "token economy" created by the proliferation of crypto-networks is still in its infancy. Quality projects represent only a small proportion of all the blockchain projects that have been created to date, but the possibility to finance projects and practices that have a positive environmental benefit is just beginning to be demonstrated.

4. Incentivizing circular economies

Today, 90 billion tonnes of resources are extracted every year to meet consumption demands and that number is expected to more than double by 2050. Estimates also predict that by 2050 there will be more plastic waste in the oceans than fish. If harnessed in the right way, blockchain could fundamentally change the way that materials and natural resources are valued, incentivizing individuals, companies and governments to unlock financial value from things that are currently wasted, discarded or treated as economically invaluable. This could drive widespread behaviour change and help to realize a truly circular economy.

Early-stage blockchain applications are being developed to reward individuals or companies with cryptocurrency credits that represent value, in return for sustainable actions (e.g. collection of ocean plastic, recycling or water conservation).For example, Plastic Bank has created a social enterprise that issues a financial reward in the form of a cryptographic token in exchange for depositing collected ocean recyclables such as plastic containers, cans or bottles.[54] Tokens can be exchanged for goods including food, water, etc. RecycleToCoin is another blockchain application in development that will enable people to return their used plastic containers in exchange for a token from automated machines in Europe and around the world.[55]

Similar mechanisms can be deployed or created for re-incentivizing markets for food, water, forests and conservation activities, even if investors have lower expectations of a financial return. Gainforest is an example of "crypto-conservation", using smart contracts to incentivize farmers in the Amazon to preserve the rainforest in return for internationally crowdfunded financial rewards. Remote sensing using satellites verifies the preservation of a patch of forest, which then triggers a smart contract using blockchain technology to transfer payment.

The potential extends beyond merely changing behaviour and could also incentivize companies to design and manufacture products in ways that make it easier to manage the product lifecycle and to reharvest materials and unlock their embedded value.

Another potential application of blockchain in incentivizing the move towards a circular economy involves its use in more traditional systems of waste management. For example, extended producer responsibility (EPR) systems incentivize the recycling of waste by transferring a fee paid at the point of purchase to recyclers in order to subsidize the cost of recycling non-profitable or even toxic materials found in products such as electronic waste. Smart contracts based on blockchain technology could dramatically increase the transparency, scalability and efficiency of this process allowing for uptake in markets where the costs of setting up EPR systems have been prohibitively high and trust in the system is low. Coalitions of companies, governments and international organizations are exploring this use-case.

An important challenge in scaling these applications will be the level of public understanding of blockchain technology, and the willingness to use it. Poor usability for retail-level users is often cited as a weakness of existing blockchain platforms and, until this is addressed, it is difficult to see widespread adoption and use of these initiatives.

Spotlight on global soft commodity value chains

The destruction of forests destroys biodiversity and creates almost as many greenhouse gas emissions as global road travel, and yet it continues at an alarming rate, with an area equivalent to the size of South Africa lost between 1990 and 2015.[56]

In addition to the environmental degradation, it poses a risk to many global supply chains, particularly those related to consumer products. Research by CDP found that in 2017 up to $941 billion of turnover in publicly listed companies was dependent on commodities linked to deforestation.[57] The production of soft commodities, in particular beef, soy and palm oil, has the largest impact on tropical forests, accounting for 36% of tropical deforestation.[58]

In response, a movement has emerged to halt, by 2020, the deforestation embedded in global agricultural supply chains. For example, the Consumer Goods Forum (CGF) pledged to achieve zero-net deforestation by 2020 from beef, soy, palm oil, pulp and paper supply chains, while more than 190 governments, non-government organizations and corporations signed the New York Declaration on Forests, committing to eliminate all deforestation driven by agricultural commodities by 2020. The US government and Consumer Goods Forum established a new platform dedicated to helping organizations achieve their deforestation-free commitments – the Tropical Forest Alliance 2020 (TFA 2020).

Now funded by the governments of Norway, the United Kingdom and the Netherlands, the TFA 2020 has identified ten priorities for stopping deforestation from commodity supply chains.[59] Of the ten, blockchain could potentially support progress in six of them: eliminating illegality from supply chains; developing and strengthening palm oil certification; addressing land conflicts, tenure security and land rights; mobilizing demand for deforestation-free commodities in emerging markets; redirecting finance towards deforestation-free supply chains; and improving the quality and availability of deforestation and supply chain data.

A number of initiatives have emerged to use blockchain as part of anti-deforestation efforts. These relate primarily to improving the tracking of carbon credits, enabling peer-to-peer carbon trading, and boosting transparency and auditability of commodity supply chains linked to deforestation.

Blockchain could also support efforts to certify the sustainability of smallholder farmers, potentially enhancing the value of their products. For example, the Programme for the Endorsement of Forestry Certification is exploring blockchain for tracing wood products[60] and IBM has partnered with Veridium Labs to turn Borneo rainforest carbon credits into a crypto token that can be traded on a decentralized exchange. Analysts estimate that around $4.8 billion was spent in the past ten years on private-market carbon credits and the initiative could make it easier and cheaper for companies to acquire and trade carbon credits and to account for their environmental footprint.[61]

5. Transforming carbon (and other environmental) markets

While many economists argue that market-based approaches are an efficient and effective way to manage environmental challenges which stem from current market externalities and failures (e.g. climate change, ozone-depleting HFCs, chemical pollution and water misallocation and scarcity), many of these market-based approaches (e.g. carbon markets) are still in their early stages of evolution, with differing standards and regulations. Blockchain platforms could be harnessed to use cryptographic tokens with a tradable value to optimize existing credit management platforms for carbon (or other substances) and create new opportunities for carbon credit transactions.

Since the inception of carbon trading, there has been scepticism over its lack of transaction visibility and traceability, differing standards and regulations across jurisdictions, and the potential for double counting.[62] Managing carbon markets on the blockchain has the potential to create efficiency in platforms, and remove many of the carbon transaction constraints. An early pilot example is China's "Carbon Credit Management Platform", developed by Energy-Blockchain Labs and IBM. The intent is that, with the introduction of smart contracts, the transparency, auditability and credibility of the Chinese carbon market can be increased. If successful, the approach could be broadened to other carbon markets around the world.

In jurisdictions that prefer a "cap and trade" carbon-trading system, a blockchain application could potentially be used to automatically align license creation, thus avoiding an over- or undersupply of certificates, and thereby keeping market prices in a policy-agreed predefined range without the need for emergency or reactive interventions.

Currently, the trade in verifiable carbon-credit transactions is constrained by economies of scale. While verified carbon offsets are typically traded and verified in bulk amounts on the voluntary carbon market, the introduction of blockchain solutions enables carbon offsets to be attached at a microscale to individual products. Ben & Jerry's is piloting a blockchain platform to assign a carbon-credit price to each tub of ice cream sold, allowing consumers to offset their carbon footprint.[63] Poseidon is another company that has developed a platform which enables consumers to offset their carbon.[64] Payment will go directly to one of Ecosphere+'s forest conservation projects – the retailer's POS system shows the carbon impact of a product (KG) and adds the price for the required carbon offset to the customer's bill.[65]

Looking further ahead, it is possible that regional or global carbon markets could be created where individuals or households could trade carbon allocations. Individuals who wanted to consume more carbon-intensive products or services would pay for the privilege by buying scarce credits from others, or by purchasing offsets, so that the overall impact on the planet would stay constant and within agreed global parameters.

Spotlight on inefficiencies in the water sector

For seven consecutive years, water has ranked among the top five global risks in the World Economic Forum's annual Global Risks Report. Over this period of time, as other risks have emerged and disappeared – including the financial crisis and chronic diseases – water has stubbornly remained. While the core challenges are well known, and much progress has indeed been made, solving the water challenge has continued to elude the best and brightest decision-makers in the world.

Today, 60% of the world's population, or about 4 billion people, live in areas of near-permanent water stress. Climate change is forecast to make water supply more erratic and unpredictable, costing regions such as the Middle East and Africa up to 6% of their GDP by 2050 due to water-related impacts on agriculture, health and incomes, while also disrupting continuity across global economic value chains.[66]

While complicated political realities and a lack of investment have inhibited progress, they have typically been underpinned by an asymmetry of information leading to inefficiencies in the allocation of water resources. Blockchain technologies could help address these challenges.

For example, blockchain applications could enable households, industry consumers, water managers and policy-makers to access the same data on water quality and quantity and make more informed decisions. Such transparency could help inform consumer decisions around when to conserve or use water. It would also ensure authorities determining water allocations are able to be more data-driven, while also mitigating corrupt behaviour in situations where there may be an incentive for local authorities to tamper with or withhold water-quality data.

Blockchain technology could also support peer-to-peer trading of water rights in a given basin, allowing water users who have enough or are willing to share their excess water resources with others in the area to do so without relying on an intermediary or centralized authority.

A new collaborative platform, Water Security Rewired, is supporting a range of stakeholders including the World Bank's Water Global Practice, governments, development agencies, NGOs and other existing initiatives, technology companies and innovators, and global companies from the ICT, infrastructure, consumer, beverage and agricultural industries. It seeks to harness the potential of blockchain and other technologies of the Fourth Industrial Revolution to overcome the current asymmetry of information and allocative inefficiencies, along with other challenges facing the water sector.

6. Next-gen sustainability monitoring, reporting and verification

Corporations face increasing pressure from investors, consumers, governments and regulators to demonstrate sustainable business models and, in parallel, to prove their environmental credentials. Their sustainability reporting and external assurance of their environmental performance is, therefore, an increasingly important aspect of good corporate management. Blockchain has the potential to transform both sustainability reporting and assurance, helping companies manage, demonstrate and improve their performance, while enabling consumers and investors to make better-informed decisions.

Blockchain has the power to enhance corporate reporting by enabling the independent sourcing and verification of company performance beyond the self-reported data often currently reported. This broader assessment would provide shareholders and other stakeholders with a more realistic view of companies' performance and impact.[67] In turn, stakeholders can then be rewarded – coupled with cryptocurrency incentives – for providing and verifying that data: for example, organic farmers in a company's supply chain verifying their interactions with a company. These methods could act to incentivize governments and corporations to deliver on reporting and other environmental strategic objectives. Furthermore, if combined with third-party measurement and verification tools (e.g. advanced satellites and sensors), this would provide independent and accurate information to support an entity's management and investor decisions, improving market efficiency and providing incentives to drive change.

Blockchain applications are also being developed to support third-party assurance of sustainability reporting.[68] There is ongoing research and piloting of applications that collate data from certification bodies in a single ledger in order to increase transparency and data authenticity. Automatic data collection and management (e.g. of GHG emissions) could be realized through smart contracts in order to access real-time, trustworthy data and minimize fraud. Improved GHG accounting via the blockchain could increase the effectiveness of carbon taxation as performance is contingent on transparent and trustworthy GHG emissions data.

An important challenge here will be the willingness of organizations to report and store often sensitive data on a decentralized network. Though deemed secure when data is stored via a private key, hacking could expose this information to sources across the network.

7. Automatic disaster preparedness and humanitarian relief

As the frequency and scale of natural catastrophes increases, in part due to a changing climate, there is an increasing need both to prepare for when foreseeable natural disasters strike and to manage better real-time relief responses, e.g. coordinating and financing rapid support and supplies to people and areas where the need is greatest. Blockchain solutions could be transformational in terms of their ability to improve disaster preparedness and relief effectiveness

Blockchain solutions are starting to be developed to realize Fourth Industrial Revolution-enabled disaster preparedness. IBM, for example, is spearheading a new initiative called "Call for Code", working with the American Red Cross, to invite developers to create new applications to help people and communities better prepare for natural disasters.[69]

Concept-stage blockchain solutions are being proposed to mobilize public and private organizations to coordinate real-time disaster relief, matching community needs with least-cost suppliers. For example, connecting suppliers of clean drinking water with the helicopter pilots delivering that water could help ensure that deliveries are scheduled at specific locations within certain time frames.[70]

To enable this solution, smart-contract technology can determine which contract offer is the best one available based on the delivery needs of the community, including quantity, price, timing and location. The smart contract can trigger acceptance of the offer, and set in motion the delivery as well as confirming the delivery has taken place. SAP is involved in working on, and promoting, these types of "pooling and sharing" solutions, which could fundamentally shift how public and private organizations can be mobilized in the event of a natural disaster.[71]

An important challenge here will be to integrate disaster preparedness and relief platforms into existing early-warning and mobilization systems, across both public and private entities. Ensuring adequate trust and resolving intellectual property (IP) and data privacy issues will be particularly important. Further challenges might arise in developing countries where IT systems might not yet be Fourth Industrial Revolution-compatible without significant investment and upgrades.

8. Earth management platforms

Many of our Earth's natural systems are under unprecedented stress with planetary boundary conditions surpassed,[72] or close to be being breached, in several areas. Blockchain may be able to facilitate the collation, monitoring and management of vast quantities of Earth-system data in a geospatial digital ledger. Once scalability has been achieved, using current capabilities, it could enable secure and trusted transactions that create value across geographies and environmental domains. New blockchain-enabled geospatial platforms are in the early stages of exploration and could monitor, manage and enable market mechanisms that protect the global environmental commons – from life on land to ocean health. Such applications are further away in terms of technical and logistical feasibility, but they remain exciting to contemplate.

Early efforts are under way to collect, manage and transact data for managing environmental habitats, including cataloguing the genetic biodiversity of species and habitats to inform conservation efforts (for both marine and land habitats). For instance, the Amazon Third Way initiative is developing the Earth Bank of Codes (EBC).[73] This is a project to create an open, global, public-good digital platform that registers nature's assets, recording their spatial and temporal provenance[74] (see break-out box: Spotlight on the bio-economy).

In terms of the ocean, a global ocean data platform is being developed to simplify free data access, enabling unbiased research and facilitating a data-driven debate. This open platform will allow any stakeholder to prioritize future roadmaps and strategies based on ocean health, providing comprehensive monitoring of ocean resources. Integrating blockchain technology with such a platform could further secure and enforce fishing rights and ease broader transactions, enabling better monitoring and response mechanisms.

On land, the security of property rights is an important issue and has implications for both human welfare and conservation. Land, therefore, appears to be a fruitful area in which to deploy blockchain. For example, in Brazil, fraud in the country's antiquated land-titling system has enabled swathes of Amazon rainforest to be cut down for soy and beef farming. Here, blockchain is being touted as a possible route to strengthen property rights.

Blockchain platforms are also being trialled for the observation of environmental conditions, including pollution levels and weather conditions. Coupled with data collection from decentralized data sources (e.g. home sensors or wearable technologies), these projects aim to increase the accuracy and granularity of monitoring and, in combination with other technologies, can improve the performance of forecasting and risk mitigation.

Given the scale and complexity of the platforms envisaged, new forms of public-private collaboration will be required to ensure trust, governance and accuracy. Navigating cross-jurisdictional regulations will also be important given the transboundary nature of many of these "global commons" efforts. Projects operating in this space will also need to be clear about when a blockchain-based database is needed and when a standard digital database will suffice. Such digital databases still tend to be cheaper and more energy efficient to operate.

Spotlight on the bio-economy

Earth's biological assets are under unprecedented threat, with one in five species on Earth now facing extinction.[75] One particularly vulnerable area is the Amazon Basin, which is home to around half of the world's remaining tropical forests and a significant proportion of land ecosystems and biodiversity. Due to a combination of deforestation, forest fires and climate change, up to 60% of the Amazon forest could be transformed to degraded savannah by 2050.[76] Already, the Amazon Basin has experienced megadroughts in 2005 and 2010 and megafloods in 2009 and 2012.

These contrasting extreme-weather events and disruptions are already having a significant social and economic impact. For example, the GDP of the Amazon Basin is currently estimated at a sizeable $250 billion per year.[77] Emerging technologies have the potential to create a new funding stream for conservation and sustainable development efforts, which can also support the livelihoods of local communities that depend on Earth's natural resources. Early efforts are under way to collect, manage and transact data for managing environmental (both marine and land) habitats.

By combining distributed ledger technologies, AI, advanced sensors and the Internet of Things, for example, the Amazon Third Way initiative is developing the Earth Bank of Codes (EBC).[78] This is a project to create an open, global, public-good, digital platform that registers nature's assets, recording their spatial and temporal provenance. By registering biological and biomimetic IP assets – while the expected volume of data amassed is not appropriate for blockchain technology in its current state – this code bank could record the provenance, rights and obligations associated with nature's assets. When value is created from accessing these assets, smart contracts could facilitate the fair sharing of benefits to the custodians of nature and for its protection.

The implications for governments, companies, research institutes and communities are far-reaching: for example, to support scientific discovery, bolster efforts to seek new solutions to incurable diseases, encourage bio-inspired innovations and improve conservation outcomes. Countries with valuable natural assets would also have an additional source of income to help protect these resources, supporting indigenous and traditional communities. More broadly, the ability to unlock the value of these assets would provide a new (economic) incentive to protect, rather than destroy, natural habitats. Overall, the EBC has the potential to drive a new, more inclusive bio-economy, creating new markets for sustainably sourced innovation and helping to implement the Convention of Biodiversity's Nagoya Protocol on Access and Benefit Sharing.[79]

Blockchain blockers and unintended consequences

Blockchain risks and challenges to widespread deployment

While blockchain offers exciting potential in terms of building a sustainable future, as with many emerging technologies, there are a number of risks to manage and challenges to overcome in order to harness its full capabilities in addressing environmental challenges.

Broadly speaking, these challenges relate to blockchain's maturity as a technology, stakeholders' trust in the technology and the blockchain network, and their willingness to invest in applications.[80] For example, doubts exist about blockchain's reliability, speed, security and scalability. Managing and overcoming the following risks and challenges will require stakeholders to work together to develop solutions that are effective, holistic, relevant and deployable.

Figure 6: High-level summary of blockchain risks and challenges

Source: PwC research

Adoption challenges

In order to be transformative in tackling global environmental issues, blockchain applications will need to be able to scale up effectively, gaining widespread industry and user adoption.

The usability of the technology is currently a crucial barrier to entry – many existing interfaces for blockchain ledgers are too complex for mainstream adoption today. Specific areas to improve include the user experience, system speed and the lack of formalized blockchain protocols

The degree to which users trust and understand the technology could also prove a barrier to adoption. For instance, investors interested in blockchain-based approaches to finance face significant barriers to participation as such investment applications require a certain degree of blockchain literacy.

Example: Blockchain enables aggregation of microfinancing by individuals to collectively fund larger-scale projects that address environmental challenges and increase renewable energy deployment. However, unless these adoption challenges are overcome, such platforms will not grow sufficiently to raise capital at the scale needed to be effective.

Technology barriers

While blockchain infrastructure and use-cases are maturing, and the start-up ecosystem is growing rapidly, the deployment of production-ready networks is still relatively sparse. There are a number of technical challenges with blockchain, and the ability to overcome these may determine the extent of its deployment over the coming years.

The decentralized architecture of the blockchain network, for instance, necessitates that for all PoW applications, every participant in the network must process every transaction. The result is that PoW applications are constrained by the time taken to process each transaction.[81]

In addition, as the size of the blockchain network grows, there will be more competition for the limited transaction capacity. Currently, this means transaction confirmations take longer and higher fees are often charged per transaction as users seek to outbid each other to ensure their transactions are processed first. Today, public blockchains such as Bitcoin and Ethereum can handle only between three and 30 transactions per second. To be able to underpin the complete energy grid, for example, a blockchain platform would need to be able to handle millions of transactions per second. For comparison, Visa circuits about 60,000.[82]

These characteristics create a scalability challenge, whereby the size of the network is constrained. In order to scale, blockchain protocols will likely need to develop mechanisms to limit the number of participating nodes (a device on the blockchain) needed to validate each transaction, without losing the network's trust that each transaction is valid.

Example: An inability to cope with a large number of users and rapidly process large numbers of transactions could, for instance, limit the adoption of blockchain in global decentralized energy systems.

Security risks

One of the essential attributes of blockchain is that it is said to be virtually unhackable due to the complex cryptography and the distributed nature of the ledger. All IT systems, however, are subject to cybersecurity risks, and blockchain is no exception.

By design, blockchain ledgers generally share more data with other participants than do traditional centralized databases, as data needs to be shared, often equally, among multiple peers. Enterprises cannot afford, however, to expose private data publicly for either legal or competitive reasons. To overcome this contradiction, access to most blockchain ledgers requires both a public and a private key. Since it is essentially impossible to access data within a blockchain without the right combination of public and private keys, this represents the strength of the system. This is also a weakness, however, as all a hacker needs are the right keys to access the data. Protecting these keys relies on the individual user storing and processing them securely, which can be daunting to users unfamiliar with the technology.

Example: Blockchain could revolutionize corporate and government reporting and assurance, along with carbon-market transactions. However, the often sensitive nature of the data being reported means that organizations may be reluctant to fully support the move to blockchain platforms.

Legal and regulatory challenges

As technologists focus over the next few years on fixing the technical limitations of blockchain and building networks that form the infrastructure layer of the crypto stack, a fit-for purpose legal and regulatory environment for blockchain must also be established and operable across jurisdictions globally. Current vital regulatory and legal challenges for blockchain scaling include:

"Distributed" jurisdiction and "networks" of laws:

Legislative frameworks are currently defined by each jurisdiction. Blockchain ledgers do not have a specific or clearly identified location for each transaction, with each node potentially being located in a different part of the world. This means it is not clear which jurisdiction a blockchain will fall under, with the potential to create complex, duplicative and, at worst, conflicting regulatory and compliance demands for entities implementing blockchain solutions. In the case of legal disputes, deciding which law(s) should be applied and which courts have the right to decide on matters will be complex.

Legal framework for legal validity:

If blockchain technology is to be successfully deployed in "smart contracts" or transactions, the legal framework surrounding contract formation and recognition will need to evolve to reflect technological developments. First, blockchain will need to be recognized by law as immutable. Secondly, the current legal basis for contract formation will need to evolve so that there can be no doubt when a "smart" agreement is deemed to be valid and enforceable.

Responsibility and Accountability:

Responsibility for blockchain technology is difficult to attribute; knowing who should be held accountable is often unclear and will depend on the nature of the blockchain's use, who is running it and how it functions (this is particularly the case for decentralized autonomous organizations, or DAOs[83]). Legal systems and regulatory frameworks will need to clarify accountability, including how to treat DAOs and attribute responsibility for their actions in a sensible manner

Data privacy:

Blockchain ledgers are immutable, meaning that once data is stored it cannot be altered. This has implications for data privacy, particularly where the relevant data is personal data. Public blockchain systems, in particular, present challenges in terms of balancing individuals' right to privacy with the concept of an open network.

The nature of blockchain systems (public and private) as an immutable record inherently contradicts the "right to be forgotten", which applies as a legal right in some jurisdictions. Where organizations are subject to these types of privacy laws, their use of blockchain to handle personal data should be carefully considered. For example, organizations storing personal data via blockchain will need to carefully consider how to comply with rules relating to their handling of that data. The current blockchain network – at least where the network is a public one – means it may be virtually impossible for organizations to control where data is transferred to and who has access to it.

Example: Cross-border blockchain platforms, such as blockchain platforms for energy or water grids, stand to face significant regulatory barriers associated with data protection. This is a particular issue for public blockchain networks that will be handling personal data.

Interoperability risks

The integration of blockchains with each other and with other IT systems will be fundamental to its success.[84] Given the early stages of blockchain development, it is only natural that there are no concrete blockchain standards. While the standards are being developed within each platform, the interoperability between platforms and with other IT systems is currently extremely limited and often non-existent.[85]

This potentially raises a costly operational challenge as users will need to set up suitable data models and blockchain-enabled business processes to incorporate new authentication and communication protocols.

Example: The complexity of global supply chains means that integrating blockchain-based traceability applications with existing management systems could prove costly and complex.

The energy consumption challenge

First-generation blockchain platforms with PoW verification (such as Bitcoin) are by design energy intensive. If such early solutions were to be scaled up without modification, they could have a significant negative impact on environmental challenge areas.

Developers recognize and are starting to address this important issue. Second-generation solutions, including Ethereum, for example, use different verification protocols and are far less energy intensive. It is expected, therefore, that as blockchain matures, its energy intensity will reduce and the opportunities for blockchain to help the planet may well far outweigh its energy-use limitations. (The energy dilemma surrounding blockchain solutions, including system-wide perspectives, is covered more thoroughly in the box: Can the Earth afford blockchain?.)

Can the Earth afford blockchain?

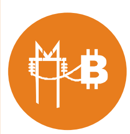
An important challenge for blockchain applications is its energy use. Currently, as the most widely used application of blockchain, cryptocurrencies are the focus of critique. Particularly in the public eye, the focus has been on the significant energy use of the most popular cryptocurrency: bitcoin.

Bitcoin energy usage

The upper estimate of bitcoin's energy consumption in July 2018 was 70 terawatt hours per year[86] – the same amount of energy as Austria consumed in 2014 and around 0.35% of total global energy consumption that year.

A single bitcoin transaction could power 1.5 American homes for a day.[87]

A Visa transaction requires 0.01 kWh of power, whereas a bitcoin transaction requires an estimated 200 kWh per transaction.[88]



A new bitcoin chain is formed approximately every ten minutes.[89]

By design, cryptocurrencies are very energy intensive because they are mined using a "proof of work" (PoW) protocol. PoW increases in difficulty as more miners enter the network seeking to profit from bitcoin's strong year-on-year price growth. The difficulty also increases by design every four years and there is a hard cap on the total number of bitcoins that can be mined, further driving up competition between miners. This increasing difficulty and competition means that miners require increasingly powerful – and energy-hungry – computers and data centres in order to compete. This equation could significantly limit the potential of mainstream cryptocurrencies.

There are many other emerging applications of blockchain beyond cryptocurrencies, with use-cases discussed in previous sections of this report. Blockchains such as Ethereum, NEO, Cardana and WAVES operate on a less energy-intensive "proof of stake" (PoS) protocol. For example, Ethereum transactions consume approximately 12–14 times less energy than bitcoin transactions.[90] Others are developing "proof of importance" (PoI) protocols, which are expected to be less energy intensive thanks to its simplified and more accessible validation process.

Other more energy-efficient validation processes for crypto-alternatives include, for example, the Chia Network, which is an ecological alternative to bitcoin that runs on a "proof of space" process. Due to its increased energy efficiency, the Chia Network enables miners to validate processes from their home computers.[91] Energy efficiencies will additionally be seen across blockchain solutions as next-generation computers, including projects such as HPE's "The Machine", aim to significantly increase computational speed and power at a lower energy usage.

There are many ways to construct and operate blockchain networks, and the mining process is not always necessary for private key networks. Consensus can be achieved in a much more energy-lean way. "Proof f authority" (PoA) networks, for example, only allow authorized authorities to validate networks. When authorities don't have to "compete" for access, as in crypto-mining, there is less energy consumption throughout the network as a whole. For example, the Energy Web Foundation, in partnership with various energy companies including Shell and Duke Energy, is currently building an energy-lean blockchain framework operating on a PoA protocol.[92]

Understanding blockchain's broader impact on the energy system overall, however, is more complicated, and it is important to adopt a system-wide perspective that takes into account the relative energy impact of blockchain solutions versus existing methods. For instance, energy management is an area where the relative energy-saving benefits of blockchain could outweigh system-energy usage. Blockchain solutions are also being developed to incentivize the uptake of renewable energy and energy efficiency (see sections: "The blockchain opportunity for our environment" and "Blockchain game changers for the Earth").

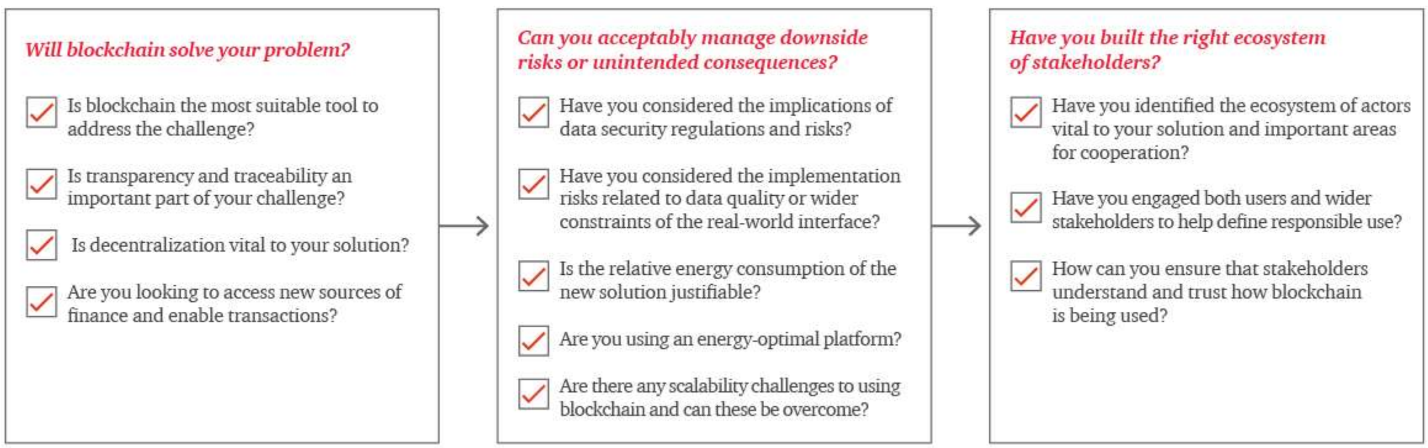
The scaling up of such solutions, if supported by the right "enabling environment", could support and potentially accelerate the overall decarburization of the energy system and global efforts to reduce greenhouse gas emissions. Examples here might include initiatives to provide proof of origin for renewable energy generated or purchased by companies, governments and individuals; renewable energy coins that reward bitcoin miners for generating or sourcing renewable energy; and efforts to crowdsource investments in renewable energy projects, opening them up to a new class of investor.

Conclusions and recommendations

Blockchain for the Earth principles

Today's excitement surrounding blockchain can lead to a temptation to try to use blockchain to solve everything. A reasoned and structured approach is needed to help practitioners assess whether and how to deploy a blockchain-based solution for a defined environmental problem and to guide investors in considering if a prospective blockchain application is actually needed or not. Below are three principles to guide such an assessment:

Figure 7: Blockchain principles



Source: PwC research

1) **Will blockchain solve your environmental or natural resource security problems?** Consider whether blockchain is actually needed to solve the problem by asking what the problem is and how might distributed ledger technology realize your envisaged solution.

   - **Is blockchain the most suitable tool to address the challenge?** Is blockchain the only solution to the problem, or are there other simpler or more appropriate tools? And in parallel, which aspect of the technology is most needed for this particular solution?
   - **Is transparency and traceability an important part of your challenge/proposed solution?** Blockchain facilitates transparent and traceable transactions. Is data on provenance, movement and ownership something that would be valuable for the solution?
   - **Is decentralization vital to your solution?** Can a blockchain-enabled decentralized solution improve environmental performance relative to a centralized system? What other advantageous decentralization characteristics does the new system need that blockchain may support, including, for example, peer-to-peer transactions, demand-supply balancing, transaction efficiency and speed, enabling participation of wider market participants (consumers and devices)?
   - **Are you looking to access new sources of finance for sustainability outcomes?** Blockchain is an enabler for accessing project finance from wider investor types (including the wider public), or creating financial value and trade from non-traditional asset classes (e.g. natural capital, water). Is this a requirement of the application? What are the distinct advantages relative to crowd-financing or other established financing solutions?

2) **Can you acceptably manage the downside risks or unintended consequences?** Consider the risks and challenges posed by a blockchain-enabled solution to the biological and institutional systems that underpin the environment or natural-resource issue in question, the technical and commercial feasibility of being able to mitigate these, and the likely time frames to be realized.

   - **Have you considered the implications of data privacy regulations and the wider data security risks?** Environmental and natural resource issues are rightly emotive and often viewed as public goods or common property resources. If the solution requires an open network and a public blockchain system – for example, a blockchain platform solution for utilities – what are the legal and reputational data privacy implications? Will personal data be stored and what are the jurisdiction-relevant regulations relevant to the platform's location that might present a challenge, including "the right to be forgotten" and the handling of personal data? What wider data security measures can be taken, including data encryption of personal data within smart contracts?
   - **Have you considered implementation risks related to data quality or wider constraints of the real world interface?** A thorough understanding of the weaknesses of the real world system is a prerequisite for developing more effective solutions. What is the quality of the underlying data, and how serious are any constraints to the validity of your solution (e.g. impact of un-monitored large scale illicit water use on peer to peer water trading permits)? Do systems, technologies, or incentives exist to ensure the data entered into the blockchain is accurate and verifiable? If not, how can you create these?
   - **Is the relative energy consumption of the new solution justifiable?** What are the relative net greenhouse gas savings of the new/proposed blockchain-enabled solution using today's blockchain technology versus the current (non-blockchain) system?
   - **Are you using an energy optimal platform** Is the blockchain platform you are planning to use the most energy-efficient option currently available while still meeting your use-case requirements? Does it allow for continuous improvement in energy use – for example, does it incentivize developers to reduce its energy use over time and as you scale up?
   - **Are there any scalability challenges to using a blockchain platform and how might these be overcome?** For example, is a data standardization effort required to enable scaling? At what scale might the platform reach transaction capacity and are there any technology platform workarounds that address the scalability challenge (e.g. a slimmed-down "light client" version or separate off-chain layers to the platform)?

3) **Have you built the right ecosystem of stakeholders?** Blockchain's value as a solution multiplies when more players participate and when stakeholders come together to cooperate on matters of industry-wide or system-level importance. New partnership and opportunities are more likely to emerge from multidisciplinary ecosystems.

   - **Have you identified the ecosystem of actors vital to participating in your solution and important areas for cooperation?** For example, participants should come together to agree a common set of rules for governance, create and implement a risk-and-control framework (including social and environmental impacts), and determine how to share costs and benefits across the community (e.g. in a blockchain solution that benefits the underserved and poorest members of the community).
   - **Have you engaged both users and wider stakeholders to help define responsible use?** Have you brought together participants and stakeholders that will be directly and indirectly impacted by the solution to understand their needs and concerns?
   - **How can you ensure that stakeholders understand how the technology is being used – along with the environmental, economic and social implications – to develop trust in its deployment?** Have you engaged with industry groups, regulators, governments, NGOs and civil-society community groups to raise awareness of, and build trust in, your solution?

Recommendations

The opportunity for blockchain-enabled innovation to benefit humankind and our environment is substantial, but the technology itself is still at a relatively early stage, with many hurdles to overcome. Far from being an obstacle, this presents an important opportunity for stakeholders to collectively ensure that the future development of blockchain technology – both technology protocols and its applications – constitute "responsible blockchain". If this is achieved, blockchain can be expected to play an important role in enabling new technological solutions to pressing environmental challenges, including climate change, biodiversity, ocean health, water management, air pollution, resilience and waste reduction. In broader terms, there is also the potential for blockchain to enable a system shift from shareholder to stakeholder value, and from traditional financial capital to accounting for social, environmental and financial capital. This is particularly important for the environment, where the "tragedy of the commons" and inadequate or non-existent valuing of financial costs present major challenges.

Harnessing blockchain technologies to drive sustainable and resilient growth and a new wave of value creation will require decisive action. The opportunities that blockchain offers need to be developed and governed wisely, with upfront and continual management of the unintended consequences and downside risks. This is a responsibility shared by all stakeholders – from the technology community (entrepreneurs, researchers, open-source developers and big tech) and industrial sector through to governments (policy-makers and regulators), international organizations, investors and community organizations. Establishing new global platforms to accelerate the creation of a "responsible blockchain ecosystem", rather than just to incubate specific projects, would be a valuable and much-needed next step. It could support the development of effective blockchain solutions for environmental challenges, help ensure blockchain technology is sustainable (i.e. good for people and the planet) and play a crucial role in formulating the necessary governance arrangements.

The following set of recommendations is therefore grouped under these three overarching themes and could provide a roadmap (or at least the starting point) for such collaborative platforms. Where applicable, this section also calls out stakeholder-specific recommendations in recognition of the fact that different stakeholder groups will often have specific roles to play within the collective effort to speed up innovation, minimize risks and maximize environmental and societal benefits from the application of blockchain.

Developing effective blockchain solutions

1) **Harness blockchain for environmental value:** While blockchain is a ledger of any transaction that involves value, the main focus is currently on financial value. However, tokenized systems create an opportunity to harness non-financial value, including realizing natural capital and/or incentivizing sustainability outcomes. Capturing this opportunity could also help to drive the next stage of sustainable growth and value creation.

   For **international organizations and multilateral development banks,** there is a clear need to create the governance, transparency and other conditions needed for blockchain applications to be successful in transforming the management of the global environmental commons. Cross-institutional collaborations could help create global frameworks while also establishing regulatory sandboxes to trial innovative approaches with particular governments, users and developers. There would be enormous benefit in establishing a new multi-agency blockchain initiative. It could, for instance, enable sustainable resource management across important value chains such as fish, soft commodities, plastics and electronics; support better management of vital resources such as watersheds and forests; improve coordination in response to natural disasters; and overcome current political and logistical blockages, for instance, land rights and localized corruption. Such an interconnected approach will be essential if the international community is to successfully harness the potential of blockchain to accelerate global environmental action and the delivery of the global environmental goals.

   For **angel investors, venture capitalists, accelerators and impact investors,** there are still relatively few blockchain applications or platforms actually in production that aim to address sustainability challenges. Yet the need and the potential are substantial. This means there is a relatively untapped investment space that could be explored. In addition, existing portfolio companies could be encouraged to evaluate whether blockchain could create both business value and positive social and environmental performance.

2) **Combine blockchain with other Fourth Industrial Revolution technologies:** Blockchain is often not a complete solution in itself – the greatest benefits will be realized when distributed ledgers and smart contracts are used in collaboration with other Fourth Industrial

Revolution technologies, including AI and IoT. There is therefore a need to recognize how blockchain can best be integrated with other solutions to address global environmental challenges.

3) **Collaborate for interdisciplinary solutions:** Blockchain's decentralized architecture means there will be a need to ensure that the views of stakeholders are accounted for in the design and deployment of platforms. There will also be a need for significantly more interaction among developers, users, policy-makers, regulators, lawyers and domain specialists to optimize the design and deployment of blockchain, in addition to developing the surrounding legal and regulatory architecture

   For **companies**, this means that realizing the potential of some of the most transformative systems-level blockchain-enabled applications will require collaboration and co-innovation across different sectors, between industry and the blockchain community, and between the public and private sectors and the third sector, such as NGOs and non-profits. This could mean co-investment in an open-source foundational, pre-competitive and shared blockchain platform for a sector. Current efforts by the Energy Web Foundation and their partners in industry and finance to build a new openly accessible digital infrastructure to help decentralize, democratize and decarbonize the energy system are demonstrating how such an approach could work.

   Research institutions experienced in multidisciplinary research will have an important role in bringing together environmental and technology/data scientists and industry practitioners, to develop knowledge on the use, impact, ethics and risks of blockchain for the environment.

Ensuring blockchain technology is sustainable

4) **Anticipate wider political economy challenges and unintended consequences:** Given the potential for blockchain to upend current well-established and centralized systems, it is important for all stakeholders to consider how changes might feed through to the economy and society, in addition to wider trust issues regarding data privacy and security. Multistakeholder dialogue will be crucial to navigate high levels of expected change, build trust and identify and manage unintended and unforeseen consequences.

5) **Deliver "responsible blockchain":** Put in place "smart" design, deployment and governance measures for blockchain solutions to ensure responsible use for society and the environment. This includes a range of measures, from ensuring compliance with privacy rights and clarification of accountability in case things go wrong through to minimizing energy consumption and incentivizing developers to contribute improvements.

   It will be important for **companies** and **developers** to actively inform the regulatory landscape and help to shape standards (see "Governance" below): this includes working together via industry bodies such as Global Digital Finance, which is working towards a harmonized set of standards (the global code) and practices for the cryptocurrency space and/or engaging directly with governments and regulators at the national level on needs in regards to blockchain governance and public-private partnerships. Crypto-relevant industry bodies such as Global Digital Finance should also look to embed sustainability considerations into the emerging industry code of conduct and principles.

   Internally, **companies** should establish board leadership of, and accountability for, blockchain and its impact on the business to ensure that their technology strategies build in and optimize the effect blockchain will have on sustainability outcomes, both to capture new business opportunities and to manage potential risks. Companies that develop an understanding at the leadership level of the barriers, safety, ethics, values, governance and regulatory considerations associated with responsible experimentation and deployment will be best placed to capture the benefits of this emerging market.

   The **developer community** in particular has a vital role to play in improving the energy performance of protocols for consensus validation, thereby addressing one of the biggest challenges to blockchain scaling: its power use. Further improvements are required for many existing platforms – and incentive structures could be built into these and future blockchain platforms – to encourage developers on open-source platforms to contribute improvements to energy performance while also helping to tackle wider challenges to blockchain scalability and performance (e.g. data encryption, light versions of the technology for distributed devices). Such open-source approaches could also accelerate and broaden the range of innovative solutions developed on blockchain platforms (e.g. provenance and tracking apps or transactive grid operations).

Mainstream institutional investors and asset managers should consider embedding sustainability considerations into their investment criteria for blockchain-related (and other Fourth Industrial Revolution) investments. This would be consistent with the methodology now being adopted by investors across other parts of their portfolio and will be crucial for managing future risk to the value of those investments. It would also encourage developers to ensure environmental considerations (such as energy efficiency) do not prevent real-world scalability of promising blockchain applications.

Formulating the necessary governance arrangements

6) **Develop an agile approach to governance and regulation:** Given the infancy of the use of blockchain technology and the speed of its evolution, governments and regulators should expect to take an agile approach. Currently, regulators in many jurisdictions have been playing an active role in monitoring developments and reacting as and when they see potential harm. However, this is on a jurisdiction-by-jurisdiction basis and firms operating blockchain-based companies (e.g. crypto-trading exchanges) can, with relative ease, move their offices, key officers and primary servers to different jurisdictions. Likewise, differences across jurisdictions, including at worst conflicting requirements, are challenging given the distributed and transboundary nature of the technology.

7) **Build a more global solution to governance, or at least a globally coordinated solution:** The distributed nature of blockchain technology accentuates the importance, in the longer term, of developing a more globally coordinated governance architecture. There are three main potential options for how blockchain could be regulated and governed more widely with recommendations presented as they apply to each:

   a. **Employing industry self-regulation.** Industry cooperation to achieve a set of common principles can be an important mechanism to raise standards.[93] In the cryptocurrency space, a number of national regulators are paying attention to the standards (the global code), practices and taxonomy being developed by the industry body Global Digital Finance. In practice, consumers and the industrial sector looking to use or rely on a firm using blockchain would be able to see standards have been adhered to, thereby supporting decision-making and building trust. A global code has the benefit of being jurisdiction-agnostic so that firms can layer compliance with other jurisdiction-specific obligations. Regulators should play an important role in shaping such a global code, representing wider interest groups, including the general public, to ensure particular groups do not dominate and that standards are not too watered down. Regulators or enforcement agencies can also subsequently hold firms (operating in their jurisdiction) to account according to these principles, especially if they peg regulation to such standards. However, self-made regulation will always be a compromise and central regulators still have an important role to play in assessing where to develop a more rigid set of requirements, including in relation to environmental performance. This will be important to avoid the blockchain equivalent of the "market failures" that have contributed to current environmental challenges.

   b. **Country-specific regulation and government policies**. Currently this appears to be the most prevalent way of governing blockchain (at least in the crypto-asset space), with local regulators asserting jurisdiction in order to combat any perceived harm. However, when countries do this in isolation, there is a risk of creating conflicting requirements. Country-led standards in regards to the energy efficiency of protocols, for instance, could play an important role in accelerating blockchain communities to adopt greener protocols. Likewise, government funding commitments could be directed towards blockchain research (e.g. ethics, social and environmental impact, and technology innovation) and development that seeks to scale public-private "blockchain for society and environment" projects and platforms.

   c. **Globally coherent regulation.** Global regulators and international governance mechanisms such as the Financial Stability Board (FSB) and G20 have important yet challenging roles to play in achieving more coherent regulation in regards to blockchain at an international level. Regulation in response to the financial crisis that stemmed from G20 initiatives and commitments could serve as a blueprint for this (e.g. the G20 Pittsburgh Summit that led to wide-scale G20 derivatives legislation). To date, the FSB has developed a framework for the G20 to monitor crypto-asset risks to the financial system[94], but it has not yet taken a broader look at cross-industry blockchain and DLT standards and codes. If international industry bodies such as the BCBS-IOSCO or FSB can come up with relatively detailed requirements for certain types of firms using blockchain, this could help achieve harmonization across jurisdictions, including in relation to environmental performance. While this would send strong governance signals to governments and companies, as the G20 derivatives reform showed, there is still a risk that implementation on a jurisdiction-by-jurisdiction basis will differ as countries look to build on existing regulations and principles, and not all jurisdictions may choose to implement the recommendations.

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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 World Economic Forum and its new Centre for the Fourth Industrial Revolution in San Francisco. It also brings Stanford University's 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:

Glossary of blockchain terms

Blockchain consists of a number of areas, including but not limited to those below:

Blockchain terms	Description
Distributed ledger	• An electronic ledger in which data is stored across a series of decentralized nodes as opposed to one centralized system. Distributed ledgers are inspired by blockchain technology. However, unlike blockchain, distributed ledgers are not tied to bitcoin or any specific cryptocurrency and may be private and permissioned.
Permissioned ledger	• Participants in this ledger system are universally known to all other participants. Permissioned ledgers can be both public or private ledgers. Read or write ability is granted to selected parties.
Permissionless ledger	• Participants in this ledger system may remain completely anonymous. Although most permissionless ledgers are public ledgers, they could also be private. Anyone in the network has read and write ability.
Consensus Mechanism	• Process by which all of the validators within a distributed ledger system reach an agreement on the state of that ledger.
Cryptography	• Science of taking information and transforming it in a manner in which it can be deciphered only by the intended recipient. Cryptography is a process used primarily to protect sensitive information.
Proof of authority	• An algorithm that validates transactions through a consensus mechanism that relies on identity as a form of stake.
Proof of Importance	• A mechanism used to determine which nodes are eligible to add a block to the blockchain, a process known as “harvesting”.
Proof of history	• An algorithm used to create a historical record that proves that an event has occurred at a specific moment in time.
Public distributed ledger	• Distributed ledger system that is open to all interested participants and can be appended by all participants. The Bitcoin blockchain is an example of a public distributed ledger.
Private distributed ledger	• Distributed ledger system in which all participants are known, and access to the ledger can be limited to approved parties.
Smart contract	• Computer protocols that facilitate, verify or enforce the execution of a contract. At a fundamental level, smart contracts are analogous to a series of if-then statements applied to the details of a transaction.
Tokens/Tokenization	• Digital representation of a real-world asset/the concept of tying information about an asset to a blockchain. From there, participants can interact with the asset by selling or trading it, for instance.

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 World Economic 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 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 technologies and research that the Fourth Industrial Revolution offers
- Design a **public-private accelerator for action,** enabling 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 to take hold and develop.

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

Annex III:

Building block(chain)s for a better planet – Use case table

Environmental challenge: Climate change

Action area	Use case	Description of the role of blockchain	Potential environmental outcomes
Clean power	*Peer-to-peer renewable energy trading systems*	Blockchain – based peer-to-peer energy platform for trading solar energy and other renewables, allowing a decentralized energy market for efficient household energy use (e.g. SunContract, SOLshare and LO3 Energy)	A peer-to-peer system reduces the need to transmit energy over long distances, reducing household energy storage needs and diminishing energy loss in the transmission phase from power plants to consumers.
	Crowd-sale for renewable energy investment	Blockchain based energy system provides a platform for people to invest in renewables that otherwise are unlikely to attract investment (e.g. EcoChain and Sun Exchange)	Users will receive a return from investing in renewable energy installations and finance is provided for renewable energy projects that require investment.
	Optimized distributed grid management	A distributed energy utilities system through which households can buy and sell energy	The distributed network aims to provide communities with affordable, reliable, and clean electricity to reduce carbon emissions at a global level.
	Authentication of renewable energy certificates	The use of blockchain for verifying renewable energy certificates (RECs) has the potential to boost buyer confidence in REC authenticity, eliminating the need for expensive third-party certifiers	Blockchain gives more confidence that the renewable energy certificates being sold represent real green power, helping to support the renewable energy market.
Smart cities and homes	*Blockchain-based land, corporate, civil and asset registries*	An accurate record of land conservation efforts can be facilitated through blockchain, increasing reliability and coverage of such activities (e.g. Bitland platform in West Africa)	This would allow for easier and more reliable identification of conservation areas, overcoming issues of corruption and other inefficiencies.
	Secure paperless transactions	An online encrypted database to facilitate the digitization of processes that currently use paper	Electronic transactions allow the complete removal of paper, resulting in a reduction of the ecological footprint of transaction processing.
	Citizen loyalty and reward platform	A blockchain-based loyalty and rewards platform can reward individuals for their 'green' contributions (e.g. recycling waste) to cities. (e.g. Nature Coin)	This loyalty and rewards platform can be used by governments to incentivize certain environmentally friendly actions from citizens.

Environmental challenge: Climate change			
Action area	**Use case**	**Description of the role of blockchain**	**Potential environmental outcomes**
	Decentralized voting platforms for climate action	A voting platform based on blockchain technology and backed with transparent crypto algorithms, enabling a secure online voting system and optimized election processes. (e.g. Polys)	This blockchain software can enable democratic, immutable and anonymous votes on environmental issues.
	Financially incentivized recycling initiative	Blockchain enabled extended producer responsibility system to incentivize recycling of waste by transferring a fee paid at the point of purchase to recyclers in order to subsidize the cost of recycling	This can increase the transparency, scalability and efficiency of extended producer responsibility systems, where start-up cost and low trust in the system are current barriers of use.
Smart transport systems	*Smart parking system for optimized mobility management*	Blockchain-powered sensors attached to vehicles for accurate, real-time detection and location of available parking spaces (e.g. NetObjex)	As parking technology advances there will be fewer cars searching for parking, which will result in a reduction of greenhouse gas emissions from road transport.
	Data ledger for optimized transport logistics	A blockchain platform can enhance public transport services by facilitating the exchange of transport services and logistics companies data (e.g. the blockchain platform Omnitude)	Optimizing transport logistics to increase efficiency of public transport and lower emissions.
	Peer-to-peer vehicle sharing	This blockchain – enabled payment system allows private car owners to get paid when sharing their journey with others (e.g. LaZooz and Arcade City)	The platform synchronizes empty seats with transportation needs in real-time, enabling better use of existing resources by reducing the number of vehicles on roads.
	Blockchain–based decentralized delivery networks	Blockchain–powered platform to capture and secure real-time road traffic information for more efficient delivery systems (e.g. VOLT)	The system is designed to improve the efficiency of delivery systems, greatly reducing the volume of exhaust emissions released into the atmosphere.
Sustainable land use	*Blockchain–enabled sustainable mining*	Cobalt is given a digital fingerprint that is then tracked by blockchain through its supply chain, giving a forgery-proof record of where it has come from (e.g. BHP Billiton)	Transparent mining operations to ensure ethical cobalt sourcing and more sustainable mining practices.
	Data ledger of environmental conditions to inform agriculture financing	In-field sensors collect data on soil quality, field applications, weather and farming practices. Blockchain data ledger for access to information (e.g. RipeIo's blockchain-based platform)	Transparent and immutable record of agricultural conditions. This is used to inform sustainable farm management.
	Automation of data collection and management for better sustainability accounting	The tool uses blockchain for an accurate verification of sustainability-related data to provide unprecedented levels of accountability.	Automating sustainability data collection and management (such as GHG emissions) through smart contracts in order to access real-time, trustworthy data and minimize fraud.

Environmental challenge: Climate change

Action area	Use case	Description of the role of blockchain	Potential environmental outcomes
Sustainable production and consumption	*Blockchain–powered platform for carbon offsetting*	The technology provides consumers with accurate information on the level of carbon offsets they're buying from products, enabling to trade up or down their own offsets (e.g. Ben & Jerry's)	By tracking the carbon offsets acquired from products consumed, and making individual's footprints visible, the platform aims to encourage more sustainable public consumption of carbon.
	Waste-to-energy blockchain solutions	Blockchain is connected to anaerobic digestion technologies that convert household waste into electricity, which can then be sold to other households (e.g. 4NEW)	The solution aims to address energy waste at a household level, enabling customers to efficiently manage energy usage.
	Ledger for collection and verification of ESG data	The global ledger ensures verifiable and immutable data on corporate sustainability to provide an accurate picture of companies' social and environmental performance.	The technology ensures an accurate assessment of a company's social and environmental performance, providing useful information that can be used to create more relevant actions for reducing impact on climate change.
	Soil properties data collation from distributed sensors	Dashboard with a transactional ledger for e-waste recycling - connecting parties involved in the recycling supply chain and increasing efficiencies.	It provides immediate data on recycling to policy makers, leading to improved resource efficiency and expenditure.

Environmental challenge: Biodiversity and conservation

Action area	Use case	Description of the role of blockchain	Potential environmental outcomes
Habitat restoration and conservation	*Cryptocurrency for investment in habitat restoration and species conservation*	Blockchain – based payment platform to facilitate the clean-up of oil-polluted lands, by providing community members with cryptocurrency payments through a secure, non-corruptible, payment system (e.g. Sustainable international platform Sela)	By rewarding active community members with cryptocurrency compensations, the blockchain-enabled platform seeks to encourage the clean-up of oil-polluted regions.
	Tracking geographic reach and movement of endangered species	Blockchain ledger to track, tag and record the health, geographic reach, and movement patterns of endangered species (e.g. The WEF Amazon Bank of Codes and Care, NGO Uncared platform in planning)	The technology is used to record real-time information on the health, locations and movement patterns of endangered species to inform conservationists on most appropriate mitigating actions.
	Incentivization for farmers to protect habitats	Blockchain-powered smart contracts to verify volunteering activities by providing financial incentives based upon individual performance (e.g. reforestation projects). (e.g. GainForest)	The solution is designed to provide financial rewards, incentivizing citizen to become stakeholders in tackling deforestation.

Environmental challenge: Biodiversity and conservation

Action area	Use case	Description of the role of blockchain	Potential environmental outcomes
Pollution control	*Recording of pesticide use on agricultural land*	Blockchain – based platform enables farmers to record the pesticides they use, how often they used them and the location of use	The platform provides the public with information on farmers' pesticides use influencing consumers' purchasing decisions and mitigating environmental impacts from agricultural activities.
	Incentivized system for responsible waste management	The platform enables users to earn coins by exchanging plastic and aluminum bottles and by sorting waste correctly (e.g. the Recereum platform)	The system aims to tackle waste sorting and management issues to ensure a safer and cleaner environment.
Realising natural capital	*Timber and other natural resources provenance tracking*	Blockchain ledger to collate and store data on the provenance of timber at a global level. (e.g. BVRio has developed a platform called the Responsible Timber Exchange)	The systems enables verification of the origin of timber, diamond and other natural resources to encourage sustainable harvest practices.
	A decentralized natural asset exchange platform	The solution permits the creation and transfer of verified and protected digital assets called 'ether' that can be used to purchase Earth tokens	An emerging online platform offering efficient, transparent and democratic connections between producers, buyers and consumers of natural capital assets, fueling demand for environmental solutions.
Sustainable trade	*Transparent monitoring of supply chain transactions*	The solution enables farmers to track real-time data and more effectively manage crops as they move through the value chain. (e.g. platforms by BanQu, AgriDigital, Grassroots and Bext360)	Blockchain has been deployed to assist farmers in monitoring and managing their supply chains, enabling efficient crop management and reducing generated waste.
	Real-time traceability of supply chains	Blockchain–powered app enables manufacturers, retailers and consumers to track products throughout their entire supply chain. (e.g. Carrefour have introduced an application)	The solution empowers consumers to make purchasing decisions that can support ethical supply chain practices.

Environmental challenge: Healthy oceans

Action area	Use case	Description of the role of blockchain	Potential environmental outcomes
Fishing sustainably	*Tracking fish provenance*	Blockchain – based mobile app for scanning tuna packaging, helping to track fish origin throughout their supply chains (e.g. WWF Blockchain Supply Chain Traceability Project)	The tool empowers retailers and consumers to select responsibly – caught fish and contributes to increasing sustainable fishing practices.

Environmental challenge: Healthy oceans			
Action area	**Use case**	**Description of the role of blockchain**	**Potential environmental outcomes**
	Monitoring of illegal fishing activities	The blockchain solution gives the ability to upload information about the global commercial fishing fleet onto a decentralized and irreversible system	More accurate information on fishing activities at a global level will enable scientific researchers, environmental advocates, and policy makers to create better management strategies for protecting marine species.
Impacts of climate change (including acidification)	*Incentivized collection of data on ocean conditions*	A blockchain – based data collection system on the pH level in water bodies, aimed at monitoring acidification, and providing insights for creating mitigating strategies where necessary (e.g. Fishcoin)	The solution enables scientists and resource managers to monitor, understand, and respond to ocean acidification.
	Incentivized investments in ocean conservation	Crypto and charity have come together to auction off items, such as digital art, to raise funds for ocean conservation (e.g. The Hondu Kitty)	This opens up new sources of finance accelerating ocean conservation efforts
	Real-time monitoring of ocean temperature and pH	Wireless sensors can monitor pH levels in the ocean and store data on a blockchain-based data platform	Climate change is likely to have a significant impact on ocean pH levels and temperature – this will monitor these changes.
Pollution Control	*Incentivized ocean plastic recycling initiatives*	Aimed at single-use plastic bottles and aluminum cans, the solution leverages a blockchain based mobile app to allow the exchange of recyclable waste for tokens, which can be exchanged for goods and services (e.g. RecycleToCoin)	Through the mobile app, individuals are more incentivized to recycle, and tokens ensure a secure and cashless method of reimbursement.
	Transparent ledger for faster, safer and more efficient shipping	A blockchain-based data platform and smart contracts can make the shipping process faster, safer and more efficient with quick paperless transactions and reliable cargo tracking (e.g. APL Ltd is testing a blockchain-based shipping platform)	Increased efficiency in shipping can significantly reduce emissions from the sector. Smart, transparent contracts can also ensure ships are applying universal safety standards.
Protecting habitats	*Decentralized and open source ledger of ocean data*	Decentralized cloud storage, built on blockchain software, for free, open-sourced data storage (e.g. Storj)	This ensures that ocean data is stored on an open blockchain so any significant or damaging changes, such as significant spikes in temperature, can be easily identified.
Protecting Species	*Fundraising for marine wildlife conservation*	Social funding and management platforms built on a blockchain can incentivize transparent, charitable investment.	Transparent and trustworthy charitable investment can encourage funding for wildlife conservation projects.

Environmental challenge: Water security

Action area	Use case	Description of the role of blockchain	Potential environmental outcomes
Adequate sanitation	*Asset-backed token system for clean, accessible drinking water*	Asset-backed token systems where users will donate 0.1% of each transaction to improving water systems in developing countries (e.g. Clean Water Coin)	Blockchain – powered payment system enabling users to contribute to providing access to clean drinking water for those in need.
	Hyperlocal water data for monitoring water quality	The platform stores hyperlocal water data that can be used to efficiently track and monitor potential water contaminants (e.g. Aquagenuity and WaterChain)	Hyperlocal water data provide actionable insight into water quality, enabling better management of water assets.
	Efficient water treatment systems	Smart contracts with a specialized water coin utilized to make industry transactions faster and transparent	Increases cost efficiency of transactions and reduces water loss.
Catchment control	*Water quality control in catchment areas*	Blockchain technology provides an immutable record of data collected by different parties on the quality of water in catchment areas.	Accurate and immutable water quality data facilitates evidence-based decision making around the allocation, quality, risks and use of water, ensuring water safety in catchment areas.
Drought planning	*Automated crop insurance for drought periods*	A blockchain – based mobile wallet offering an automated crop insurance smart contract that protects farmers against droughts, floods and tropical cyclones.	The phone – based automated insurance system enables farmers to sustain their farming activities when natural disasters occur.
	Precipitation intensity monitoring and forecasting	Decentralized weather sensors can measure precipitation intensity and forecast future weather, storing the data on a public blockchain.	A blockchain – based data platform can ensure precipitation data is available for optimized drought planning.
Water efficiency	*Blockchain – enabled peer-to-peer trading of excess water resources*	A blockchain platform to collect data from smart metering of water and convert water rights into digital assets that can be traded (e.g. AQUA rights)	The creation of a trading system can make water usage more efficient.
	Cryptocurrency-enabled smart meters	The blockchain solution will be able to help city planners better allocate water supply in areas with minimal infrastructure.	The system encourages people to adopt sustainable water practices.
Water supply	*Water monitoring and management*	Leverages smart contracts and a token management system to ensure efficient use and distribution of water (e.g. Civic Ledger has developed Water Ledger)	Enables consumers to make informed decisions around when to conserve water, and ensures transparency around water availability and quality.

Environmental challenge: Water security

Action area	Use case	Description of the role of blockchain	Potential environmental outcomes
	Micro-payments for water meter donations	Blockchain enabled donations by a large number of individuals, for instance to finance specific water meters (e.g. Bankymoon)	Transparent record for management and tracking of donations, providing confidence, and incentivizing individuals to fund smart meters.

Environmental challenge: Clean air

Action area	Use case	Description of the role of blockchain	Potential environmental outcomes
Clean fuels	*Cryptocurrency payments for EV public charging*	Mobile phone app linked to a blockchain-based network to provide electric vehicle (EV) owners with a seamless charging system that manages the payment process automatically (BlockCharge is a working prototype for electric vehicle charging created by RWE and Slock.it)	The innovative charging system provides readily – available infrastructure to incentivize uptake of EV's for reducing harmful emissions into the environment.
	Enabling safe and reliable AV implementation	Blockchain encourages the uptake of autonomous vehicles (AV) through providing more accurate safety information, bringing forward the safety, efficiency and convenience benefits of autonomous driving technology	The secure ledger platform provides important information on autonomous vehicles to accelerate its adoption and encourage the use of sustainable transport modes.
Early warning	*Automated air quality monitoring system*	An openly governed platform to track companies' air quality and emission emitting sources	A blockchain – based asset management system to help businesses around the world monitor and manage their emissions of carbon and other pollutants
	Early detection of toxic chemical leaks	Portable, user friendly air sensors powered by blockchain to detect and store the level of air pollution in buildings.	The solutions provides users with timely information in an accessible way to encourage mitigating actions where necessary, enabling health and climate change issues to be tackled.
Filtering and capturing	*Air pollutant data collation from distributed sources*	Network of interconnected devices to collect air pollution data and transfer pollution levels onto a decentralized network that is accessible through a subscription payable in crypto-currency. (e.g. Filament developed The Tap, and AirBie Blue)	Citizens and governments who have access to accurate information on air quality can take meaningful actions to fight air pollution.

Environmental challenge: Clean air			
Action area	**Use case**	**Description of the role of blockchain**	**Potential environmental outcomes**
Monitoring and capturing	*Intelligent methane monitoring systems*	Smart decentralized sensors can be deployed near natural gas extraction wells and along distribution pipelines to detect methane levels in the air (e.g. IBM)	Methane is the second largest contributor to global warming after CO^2 and early detection and monitoring of methane levels can reduce methane in the air.
	Local and real-time monitoring of particulates and NO^2	A decentralized peer-to-peer network to store and monetize real-time pollution data, allowing those who host sensing equipment to be rewarded. (e.g. the live-streaming data platforms Streamr and Smart Citizen)	The system aims to incentivize community participation in monitoring air quality by providing a monetary reward system for sharing data on the pollution level of specific locations (e.g. households).

Environmental challenge: Weather and disaster resilience			
Action area	**Use case**	**Description of the role of blockchain**	**Potential environmental outcomes**
Early warning systems	*Real-time monitoring of natural hazards*	IoT, blockchain and advanced sensor platforms together with predictive AI analytics to monitor real time natural hazards such as tremors and sea level changes.	Alerts for hazard response in order to ensure more resilient communities.
	Decentralized weather sensors generating automated alerts	Decentralized weather cameras and sensors can provide accurate, local weather data through a blockchain platform - generating alerts in periods of extreme weather (e.g. Weatherblock)	Local weather monitoring enables alerts for hazard response.
Financial instruments	*Management of transactions in response to extreme weather event*	Blockchain to streamline and validate transactions during extreme weather response instances.	Provide efficient and effective disaster response, in order to minimise the impact on local populations
	Disaster recovery funding	Smart tokens to transfer cash to disaster victims, coordinate the delivery of supplies, streamline humanitarian financing, or make humanitarian projects more gender-inclusive (e.g. Givetrack)	Traceability in donations to increase donor confidence and better manage the distribution of aid.
	Crowd-sale for adaptation investments	Blockchain-enabled platforms and processes could seamlessly manage complex financing environments that integrate a wide number of stakeholders (e.g. Crowdwiz's WizFund)	These attributes make climate-related, infrastructure and other sustainable development projects more attractive for investment.
	Decentralized disaster insurance platform	Decentralized blockchain-based insurance platform, using smart contracts to provide automated premium calculations and claims payouts (e.g. Etherisc)	Facilitates faster claim payouts after extreme weather events.

Environmental challenge: Weather and disaster resilience

Action area	Use case	Description of the role of blockchain	Potential environmental outcomes
Prediction and forecasting	*Extreme weather impact analysis*	Access to weather information has always been fairly constrained and costly. With blockchain technology it is possible to offer different "tiers" of accessible information, depending on what consumers want.	Blockchain-enabled platforms and processes could seamlessly manage complex financing environments that integrate a wide number of stakeholders
	Ledger to identify, verify and transact weather data	The platform stores real-time weather data captured through smart weather camera stations for actionable insights on extreme weather events (Weather Block)	The system provides accurate location-based weather forecasting to improve community preparedness ahead of extreme weather events.
Resilience planning and disaster response	*Enhanced emergency disaster response*	Fund management platforms that use permissioned blockchain to help donors, governments and NGOs transfer and trace funds through a value chain	The system makes the delivery of development and humanitarian aid more effective.
Resilient infrastructure	*Decentralized mini-grids improving disaster resilience*	Using a blockchain load management system with a peer-to-peer trading platform, mini-grids can become more prevalent	Decentralized mini-grids are more resilient against natural disasters than an ageing centralized grid.
	Automatic rerouting of power to prevent blackouts	Blockchain enables the creation of microgrids which are better able to respond to failures (and prevent blackouts) than traditional grids (e.g. LO3)	This system makes power grids more resilient to blackouts, enabling them to reroute power if part of the grid or generation units are damaged by extreme weather or disaster.

Endnotes

[1] A blockchain is a decentralized ledger of any transaction involving value that is an interlinked and continuously expanding list of cryptographically secure, immutable data, and is updatable only via consensus.

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