Schneider Electric™
Sustainability Research Institute

Green Digital Solutions for Corporate Biodiversity Action

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Introducing the Schneider Electric™ Sustainability Research Institute

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Global awareness for a more inclusive and climate-positive world is at an all-time high. This includes carbon emissions as well as preventing environmental damage and biodiversity loss.

Nation states and corporations are increasingly making climate pledges and including sustainability themes in their governance. Yet, progress is nowhere near where it should be. For global society to achieve these goals, more action and speed is needed.

How can we convert momentum into reality? By aligning action with United Nations Sustainable Development Goals. By leveraging scientific research and technology. By gaining a better understanding of the future of energy and industry, and of the social, environmental, technological and geopolitical shifts happening all around us. By reinforcing the legislative and financial drivers that can galvanize more action. And by being clear on what the private and public sectors can do to make all this happen.

The mission of the Schneider Electric™ Sustainability Research Institute is to examine the facts, issues, and possibilities, to analyze local contexts, and to understand what businesses, societies and governments can and should do more of. We aim to make sense of current and future trends that affect the energy, business, and behavioral landscape to anticipate challenges and opportunities. Through this lens, we contribute differentiated and actionable insights.

We build our work on regular exchanges with institutional, academic and research experts, collaborating with them on research projects where relevant. Our findings are publicly available online, and our experts regularly speak at forums to share their insights.

Set up in 2020, our team is part of Schneider Electric, the leader in the digital transformation of energy management and automation, whose purpose is to bridge progress and sustainability for all.

This paper from the Sustainability Research Institute builds on a previous one called *The Why, What, and How of Corporate Biodiversity Action*, published earlier this year. In this deeper dive, we will explore what technological disruption can mean for concrete biodiversity action, if applied in a purposeful and systemic way. The key strengths of the most promising modern and emerging digital solutions are discussed, and how they can be used so that they complement each other optimally. Additionally, we will cover how these technologies work best together with humans, given our own unique capabilities, and all in service of a thriving society and natural world.

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Executive summary

The urgent imperative for organizations across the world to act on biodiversity loss, including corporations, has been convincingly detailed in much research by now. The Schneider Electric Sustainability Research Institute made its own contribution to this work with the paper The Why, What, and How of Corporate Biodiversity Action, intended to help companies get started with meaningful biodiversity action.

This follow-up report builds on that starter paper by zooming in on what such actions can look like concretely, specifically when powered by one essential element of all that will be needed to reverse biodiversity loss: new digital technologies. The major digital technologies discussed in this report are artificial intelligence (AI), blockchain, eDNA, Internet of Things (IoT) and the Internet of People (or: World Wide Web).

AI technology poses the ability to analyze large datasets at unprecedented speed, resulting in relevant and actionable information. In biodiversity, this offers high potential for both nature-positive practices and all levels of the conservation hierarchy of avoid, minimize, restore, and offset. Applications include greatly enhanced monitoring capabilities, not just of species populations and habitat integrity, but also of production processes, resulting in significant reductions in resource use as well as carbon emissions and other waste generation.

Blockchain is an encrypted ledger by which information is stored and delivered, with a key attribute of enhancing trust levels in its accuracy and traceability in industrial processes and transportation. This makes blockchain valuable in the new frontiers of corporate biodiversity action of comprehensive supply chain mapping, reliable biodiversity offsetting, and circular offerings by enabling things like material passports. In this way, blockchain offers potential for nature-positive products as well as each level of the conservation hierarchy, except for the first one where biodiversity impacts are completely avoided.

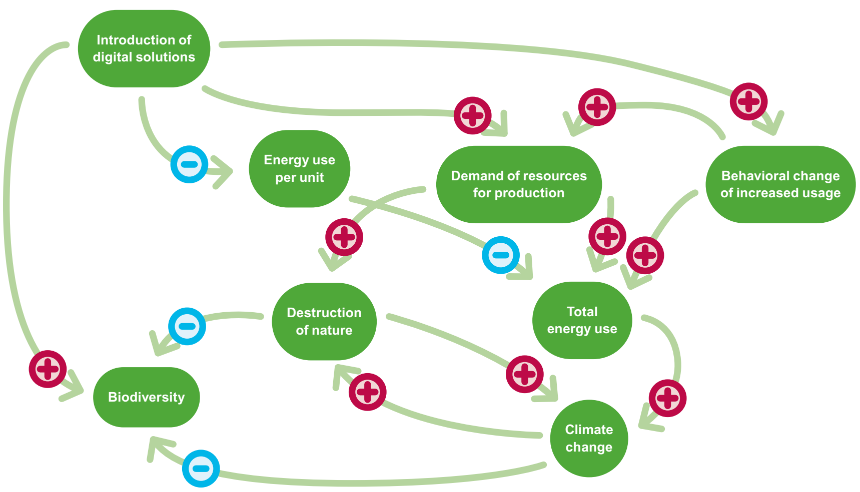
eDNA is a technique for identifying cellular material shed by an organism in the environment, by analyzing a sample of virtually anything, including snow, water, soil, or air. Because eDNA allows analysis of species far away and across vast spaces without ever coming into physical contact with them, it offers high potential especially for avoiding and minimizing biodiversity loss.

IoT refers to a system of sensing, processing, or computing devices (the “things”) that connect and exchange data with one another over a communications network. The ability of IoT to collect more data from a broader variety of sources and more remote places than humans can, enables more detailed tracking in a whole host of settings, not just in ecosystem monitoring, but also in regenerative agriculture, circular manufacturing, and green buildings. IoT thus offers high potential for all levels of the conservation hierarchy as well as nature-positive business.

Finally, the **World Wide Web** offers opportunity for humans to educate themselves and mobilize around biodiversity issues, and to be introduced to nature-positive products. The highest potential of the internet lies in conservation, especially when it comes to avoiding and minimizing impacts, by allowing people to access databases from anywhere for research and analysis, and sometimes contribute to them with data that can be highly complementary to the data collected with above-mentioned technologies.

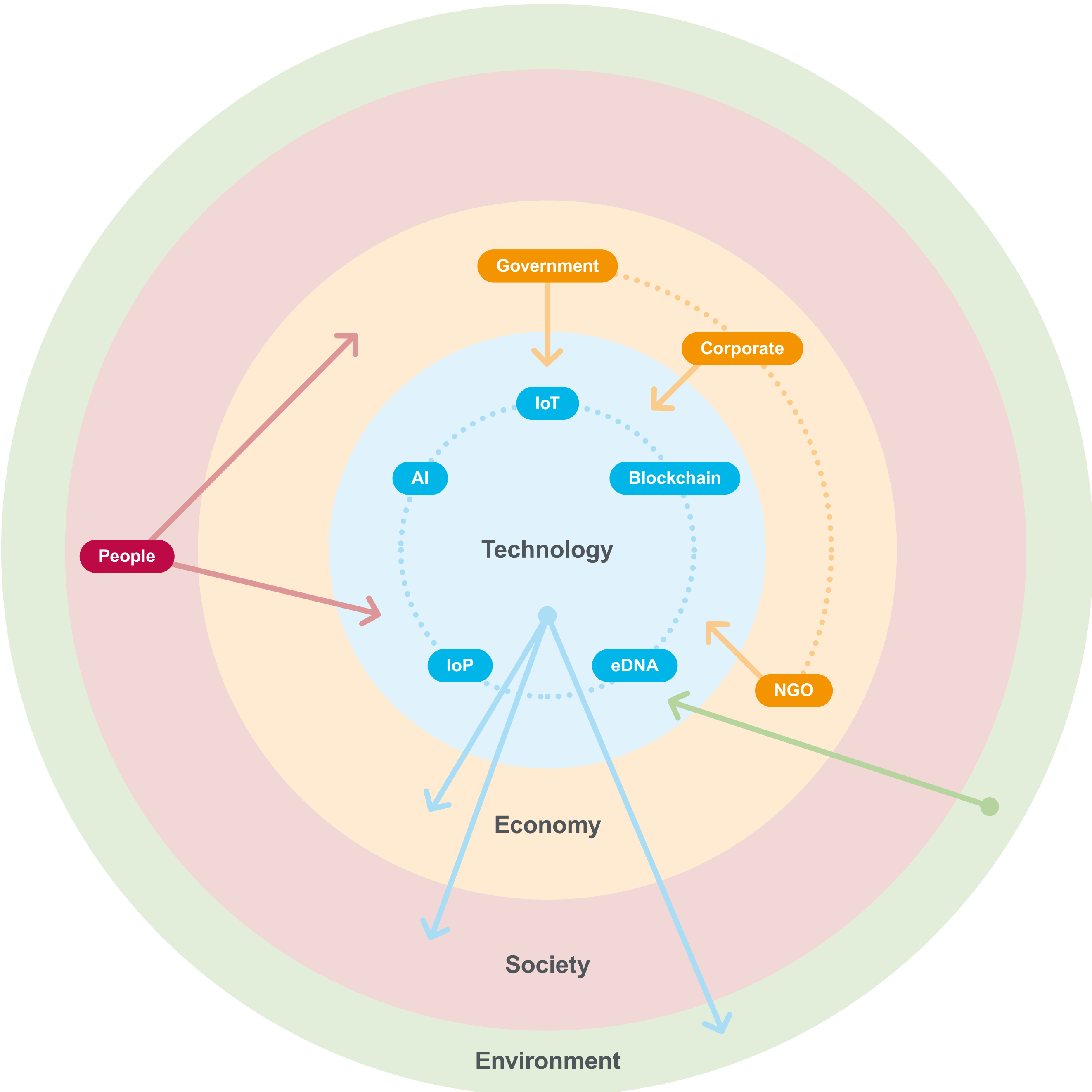
Although each individually productive, the abovementioned technologies demonstrate significant synergy when put together, as they complement one another’s functionality to optimize data collection, sharing, and analysis. For truly optimal results, though, these technologies are deployed not just in combination with one another, but also with human beings. People freed from laborious and repetitive tasks are enabled to derive new insights from the improved information that digital solutions provide. They can then make strategic decisions about what biodiversity action makes the most sense where, based on analysis that includes a systemic view. This means considering possible unintended consequences, such as rebound effects in total energy and resource use resulting from behavioral changes spurred by the introduction of the digital solution, as depicted in the below causal loop diagram.

Figure 1. Causal loop diagram depicting interactions around introduction of digital solutions. The relative strength of the different connections is what determines if the digital solution on balance has a positive or negative impact on biodiversity. By Gaya Herrington.



Including the systemic lens in the benefit analysis of a digital solution also means incorporating the broader governmental and societal system, such as nature-related policies and synergistic social benefits through working with the local community, including when relevant engaged citizens and indigenous people. In practice, this often means collaboration between corporations, government, and NGOs for the best results. Ultimately, the most effective corporate biodiversity action with a sufficiently large impact comes down to the optimal combination of technologies as well as human players, working together in an environmental stewardship that co-generates economic, ecological, and social benefits.

Figure 2. Tech and the players in the technological, economic, societal, and environmental systems. Dotted lines indicate the connected entities working together, the arrows indicate input or benefits delivered. Visualizes how optimal combination of digital technologies in the inner circle (the technology sector) supported with the right government policies, and deployed with collaboration between individuals, local community, companies, and/or NGOs in the larger economy (the second inner circle), delivers value, including biodiversity preservation and restoration, for the outer two circles (society and nature).

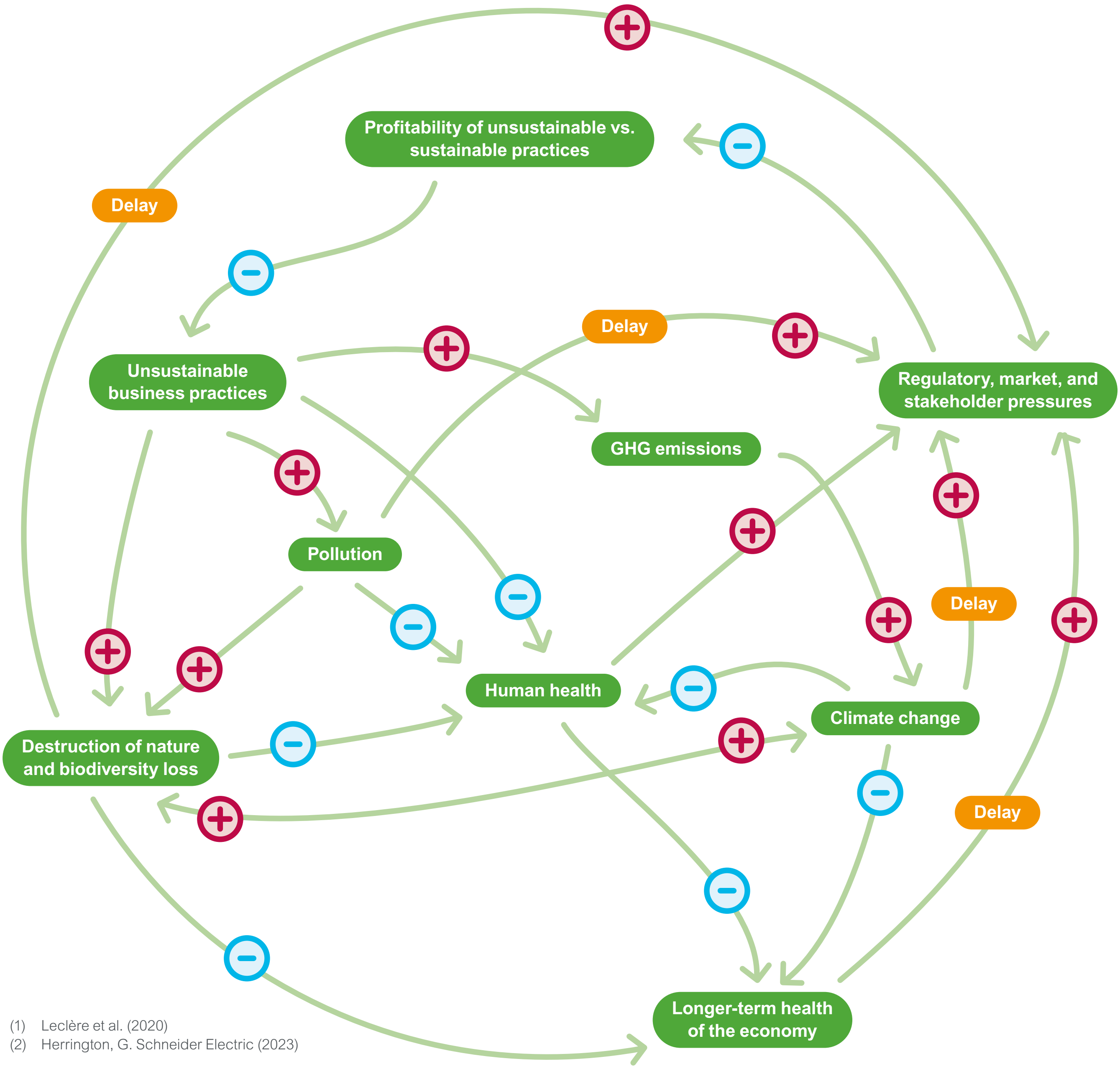


Introduction

The massive and accelerating loss of biodiversity is one of today's key crises. Current business-as-usual threatens the future of the socio-economic business model we have built, and indeed of that the living, humans and non-humans alike. What is necessary is not just a halt in biodiversity loss, but "bend the curve" towards where society has started to positively restore biodiversity by 2040[1]. In March 2023, the Sustainability Research Institute tried to contribute to meaningful corporate biodiversity action by, among other things, its paper The Why, What, and How of Corporate Biodiversity Action[2].

The paper served as a starter guide, by describing the general first steps corporations can take, including proper footprint assessment, measurement frameworks, organizational aspects, and reporting. The starter paper also applied the systems lens by putting such corporate actions within any organization's regulatory and economic environment. As depicted in a causal loop diagram, copied below in Figure 1, when we consider how interlinked business is with the wider society and ecosystems, it becomes apparent that the

Figure 3. Causal loop diagram. The double dashes indicate a delay in the feedback. By Gaya Herrington.



(1) Leclère et al. (2020)
(2) Herrington, G. Schneider Electric (2023)

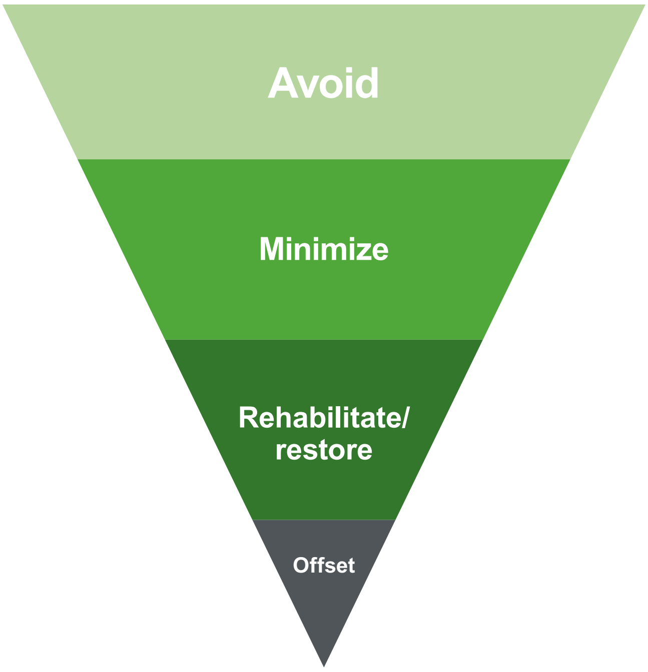
world's reliance on nature extends far beyond social responsibility, into urgent necessity for global economic and broader stability. Policymakers, regulatory bodies, customers, and other stakeholders are becoming increasingly aware and demanding on biodiversity performance as a result, contributing to an already dynamic business environment. At the same time, in addition to fortifying the imperative for corporate biodiversity action, many of these developments offer business opportunities too.

This paper builds on the previous one. The imperative and opportunities for organizations, including corporations, to act has been described in detail in that starter guide already, as well as by many biodiversity researchers, and so after this introduction will not be repeated anymore. Instead, this follow-up paper dives into what concrete biodiversity action can look like when it is bolstered with the clear business trend of technological disruption. In that sense, the focus in this paper is on the top two green-colored events in Figure 1, specifically, what modern or emerging digital innovations can mean there. How can new technologies help in biodiversity conservation, to counteract unsustainable business practices? And, on the other hand, how can some of these be used in new nature-positive business products and services, making use of the growing profitability opportunities there?

What digital solutions hold the greatest promise for corporate biodiversity action, and why, will be discussed first. Emphasis is also placed on new frontiers in corporate biodiversity action as laid out in the last paper, namely supply chain mapping, biodiversity offset credits and an advancing a circular economy that benefits local ecosystem and communities through new regulations, which are widely expected after the UN post-2020 global biodiversity framework was adopted in December 2022. It was also pointed out in the starter paper that, their potential notwithstanding, nature-positive products and services cannot compensate for conservation efforts. Conservation efforts are an essential part of biodiversity action, and so the potential for conservation and nature-positive business will be assessed separately for the technologies in this paper.

Any meaningful biodiversity conservation strategy follows the conservation hierarchy, shown in Figure 2 below. This hierarchy dictates that firstly and mostly, natural destruction should be avoided, secondly, damage that cannot be avoided is to be minimized, thirdly, damage caused must be restored when possible, and only after that, as a last resort, one should offset the remainder of damage with biodiversity credits. Given the importance of the hierarchy to elevate biodiversity action from PR to strategy, the technology descriptions cover the potential for each level of the conservation hierarchy.

Figure 4. The conservation hierarchy.



The systems lens is applied too, in several ways, including by how these new technologies interact with one another, humans, and the larger society. As the many examples that accompany the technology descriptions will illustrate, biodiversity action will have to leverage not just the synergy between modern and emerging digital solutions, but also between different societal players, including corporations, governments, NGOs, and citizens.

1 What are the major digital technologies?

Artificial Intelligence, blockchain technology, eDNA, the Internet of Things, and the World Wide Web are technologies that have completely altered everyday processes of the world. By utilizing their unique characteristics to quicken data analysis and review, securely record information, detect and collect environmental data, and bolster the ability to share findings, corporate biodiversity action can be revolutionized.

Artificial Intelligence

Artificial Intelligence (AI) is a digital technology that combines computer science and vast datasets to problem solve. AI takes data that is already available to it or that it is programmed to have access to, and runs several algorithms that will put forth an answer or solution efficiently. AI also can learn as its program runs longer and picks up behavioral patterns and features. In the biodiversity setting, AI holds potential for circularity, including boosting resource efficiency and reuse of materials. Additionally, AI can vastly enhance the speed by which industrial as well as analytical processes are completed, when it comes to analysis sometimes in real-time. AI can thus save much time and resources in biodiversity efforts, and monitor whether certain efficiency or conservation targets are truly met.

One example of how AI boosts materials reuse is the waste sorting and tracking company Greyparrot AI[3]. Greyparrot uses AI computer vision software to standardize the transparency and processes of recycling. Greyparrot seeks to identify inefficiencies in waste or sorting facilities by identifying what items are comprised of what, and labeling where that waste should be disposed – all much more efficiently than humans. This has resulted in significantly higher recovery rates of recycled materials compared to traditional sorting methods, saving their customers hundreds of thousands of dollars in some cases.

AI's capability to reduce the amount of required material resources and time also holds promise for conservation. Available resources for biodiversity conservation are typically limited, AI can assist in reducing the need for these resources as well as in allocating them to the most critical areas. This way, AI can play a role in each level of the conservation hierarchy, since it can help avoid development in sensitive areas, monitor minimization of impact, identify areas of potential restoration, and verify offsetting goals.

One such example of how AI optimizes resource use and allocation is through the Conservation Area Prioritization through Artificial Intelligence, or CAPTAIN, which is an AI based technology that uses computer models and data to identify potential avoidance, minimization, restoration and offsetting locations[4]. The AI takes a broad array of data including satellite imagery, pre-existing data sets, and field surveys, and then uses its processing ability to aids scientists and conservationists in determining which efforts would be most effective where, prior to employing them. Another example is the use of a subset of AI called Convolutional Neural Networks. This program uses transfer learning to identify plant and animal species with human-level accuracy, but at much faster rates.[5]

Another example of how AI can be used to minimize impacts in a credible way, is its application in a project to track puffin populations in areas for potential wind farms in the Isle of May, launched by companies Microsoft and SSE[6]. SSE can see the analysis results from the AI and determine a plan for mitigating or minimizing disruption to the habitat of the vulnerable puffin species.

Figure 5. Puffins in the Isle of May.

By using algorithms that can arrive at an answer more quickly than humans, AI can further streamline conservation efforts across different parties. Because AI makes biodiversity action data-driven and focused, interested parties can be served with the most critical information, thereby not just enhancing digital efficiency in one organization, but collaboration between organizations across the conservation ecosystem and beyond. One can see how this could be of use in apprehending poachers, when their movements are predicted by probability analysis and their presence is detected using facial recognition software, and this information subsequently transmitted to several human parties like law enforcement, conservationists, and/or policy-makers[7].

(3) GreyParrot (2023)
(4) Silvestro, D. et al (2021)
(5) Go, A. (2022)
(6) Get Nature Positive (2023)
(7) Kwok, R. (2019)

Blockchain Technology

Blockchain technology is most recognized as the software behind cryptocurrency, but this program has widespread applicability across any sector that requires security and traceability, including conservation and biodiversity monitoring. Blockchain is a digital ledger that records transactions or information and delivers it in a way that is unable to be altered or tampered with by unauthorized parties. It delivers information using "blocks", which are groups of data that are strung along in a digital chain that provide a chronological trail which is near impossible to be modified. Blockchain operates publicly, privately and with a hybrid of the two. The public blockchain is available to anyone and can be modified by no one. The private blockchain is available only to an invited individual or group, in which those with permission can authenticate or alter information delivered on the blockchain. It is this private blockchain that can strengthen sharing efficiency and reliability, resulting in a more dependable tracking method[8]. Blockchain can thus have major benefits to any biodiversity effort that may otherwise suffer from a lack of transparency and trust. Think of situations where the decision-makers on the investment in the effort are located far away from the prospective area for conservation, as is often the case with biodiversity offsetting. Or, imagine biodiversity impact tracking across supply chains that span the globe[9]. With increased traceability and transparency, not just the company but also consumers would be able to verify the ethicality of a good, a feature that is increasingly important to them. A study by the EY Future Consumer Index found that 43% of global consumers want to purchase goods or services from ethically conscience companies, even if these products or services cost more, and 61% want more information on the sustainability of these goods or services prior to purchase[10].

An example of blockchain used in a nature-positive business model is the electronics manufacturing company Fairphone. Fairphone produces smart phones by sourcing recycled materials, which are tracked through blockchain. This information is also shared with the customers via a material passport which lays out where the components of the phone came from. Because of the increased transparency, as well as a design geared towards repairability instead of planned obsolescence, the Fairphone's lifespan is increased by two years – a significant bump given the average phone's lifespan of less than 3 years[11, 12]. Blockchain also offers marketable energy reduction solutions, including the facilitation of connecting small producers with consumers, and of energy use-tracking through interconnected sensing devices (see the Internet of Things section). Both these solutions reduce carbon emissions which lessens climate change, one of the key drivers of biodiversity loss[13]. The transportation company Maersk also cut much waste and energy use (as well as costs) using blockchain, by connecting container logistics industry participants along routes on a secure platform, thereby greatly enhancing information exchange and operational efficiency along routes[14].

Blockchain also applies readily to the conservation hierarchy, as the traceability that blockchain provides can support minimization, restoration, and offsetting. Examples of the latter will follow later in this paper. When it comes to minimization and restoration efforts, blockchain use shows especially high potential in the supply chain. According to McKinsey, 90% of global impact on air, land, water biodiversity and geological resources can be attributed to consumer companies' supply chains[15]. Supply chain traceability allows corporations to assume a "bottom-up" approach to impact reporting rather than a "top-down" one, providing a more accurate picture of the biodiversity impacts of their sourcing. Other than traditional methods like barcodes, shipping labels and email[16], blockchain can pinpoint a location of biodiversity loss on the supply chain, allowing for specific, localized mitigation and/or restoration plans.

Consumer goods company Unilever, as one example, recently deployed GreenToken, a private blockchain, to promote transparency in its palm oil supply chain. This digital token contains several characteristics, including the origin and method of sourcing of the palm oil, and enables tracking through the chain of custody as it moves through the supply chain[17].

Another example of blockchain being used for minimization is within the tuna fishing industry. Bluefin Tunas are one of the most overfished species in the world. It is estimated that about 3% of Bluefin Tuna biomass remains, and this is due to Illegal, Unreported or Unregulated (IUU) practices. Unfortunately, IUU fishing is currently a massive contributor to the seafood market, accounting for 1/5 of global catch, or up to about 23 billion USD every year[18]. The losses from IUU are estimated at 50 billion USD[19], meaning that the negative impact on biodiversity and society would be more than twice the privatized gains. To counteract harmful practice, the company BCG Digital Ventures together with the World Wildlife has devised a solution using blockchain[20]. A legally caught tuna will be assigned a ledger that will remain on it from "bait to plate". A customer or consumer can minimize their impact on biodiversity by accessing an online platform to confirm it was sustainably and ethically caught, and money will return to fishers that are legally harvesting this species. After its success with tuna, this method has been extended to coffee farmers and deforestation-free palm oil, and is proposed to extend to other marine life such as seabass and prawns, as well as the dairy industry[21].

Figure 6. A school of yellowfin tuna.

(8) Seth, S. (2022)
(9) Parmentola, A. et al. (2021)
(10) Engelsted, S., & Darre, M. (2022)
(11) Iyer, H (n.d.)
(12) Turner, A. (2023)
(13) Parmentola, A. et al. (2021)
(14) Suyambu, G. T. et al (2020)
(15) McKinsey & Company (2016)
(16) IBM (2023a)
(17) O'Donnell, J. (2022)
(18) United Nations (2023)
(19) Matsakis, L. (2018)
(20) BCG Digital Ventures (2023)
(21) World Economic Forum (2020)

eDNA

Environmental DNA, or eDNA, is a survey method in which DNA that is naturally shed by organisms is extracted from the environment and analyzed to reveal something about the region or subject it was collected from[22, 23]. DNA that is shed by an organism into their habitat is collected by various obtainment methods and then analyzed with the so-called Droplet Digital Polymerase Chain Reaction (DDPCR) Technology and a metabarcoding, which takes the genetic markers on the strand of DNA and compares them against a pre-existing database[24]. This DNA can be collected from anything, from a water or snow specimen to an air or soil sample. The insight attained from these eDNA samples can infer trends in species distribution and population information. It can alert to the presence of new species, endangered species, and invasive species, without disrupting any of these subjects. eDNA overcomes several challenges that biodiversity protection faces. One is that it lessens the need for much of the labor-intensive practices that traditional survey methods require, which allows this labor to be reallocated elsewhere. It also broadens the information available to researchers because a single sample can contain DNA from multiple organisms and species. Another major obstacle that eDNA removes is the difficulty or impossibility of surveying species that are elusive or rare, or surveyance in vast, remote or harsh environments. For example, surveyance with traditional methods was previously difficult to impossible in the ocean because of its sheer vastness, whereas now simply some ocean water can serve as an eDNA sample.

Figure 7. Vial of water displaying potential detected species by eDNA.

Although the potential for eDNA in a nature-positive business model is yet to be explored, it has already demonstrated significant benefits for conservation, in particular the avoid and minimize levels of the hierarchy. The alert of species presence that eDNA provides, allows corporations and individuals to limit or eliminate disturbance to that area. For one example, eDNA has already been utilized to provide valuable insight into polar bear behavior and protection. Polar bear monitoring in a traditional survey style is particularly difficult because they are aggressive, isolated, and live in cold environments, so a long-term observance of this creature is a hardship on both the researchers and the polar bear. Researchers with the World Wildlife Fund have now taken eDNA that is left behind on the snow in polar bear tracks and can identify individual polar bears and track their movements. Particularly with the habitats of polar bears rapidly diminishing, this non-invasive research method will provide valuable insight into their adaptation to climate change and allow for surveyors to limit or eliminate their impact on polar bear lifestyle and habitat.[25]

This survey style is also effective in whole ecosystem monitoring which is crucial for understanding and tracking biodiversity. Researchers from The Globe Institute at the University of Copenhagen gathered airborne DNA particles in a Danish Forest from the atmosphere over a 3-day period. Despite only observing four species while out in the field, the data collected by the vacuum and then sequenced by eDNA revealed the presence of 64 species including several species of domestic animals and several species of wild animals. Researchers think that the data gathered by this study method can be useful for tracking anthropogenic impacts on species distribution, potential spreading of disease, and avoiding disruption to vulnerable species.[26]

Figure 8. Polar Bear on ice in Svalbard, Norway.

(22) Thomsen, P.F. & Willerslev, E. (2015)
(23) World Wildlife Fund (2023)
(24) Capo, E. et al. (2020)
(25) Rozell, N. (2023)
(26) Sexton, C. (2023)

The Internet of Things (IoT)

The Internet of Things (IoT) refers to a system of sensing, processing, or computing devices (the "things") that connect and exchange data with one another over a communications network (such as the internet). The data from the devices, such as motion detectors, cameras, flow rate sensors, connected cars, or smart phones, is shared in the IoT cloud and transmitted back to users, sometimes after analysis.[27] Buildings, leisure, agriculture, and transportation are a few of the many sectors that are revolutionized by a broad variety of smart and wireless technology that shares data instantly, and biodiversity can benefit too.

There are many devices that can sense and send information, but the below ones deserve specific mention for their broad applicability and potential for meaningful biodiversity action.

Remote Sensing, satellites, LiDAR, and Unmanned Aerial Vehicles

Remote Sensing is the acquisition of information from a distance, such as aerial images or data, and subsequent mapping and analysis to provide insights on biodiversity trends and hotspots. These IoT technologies thus can support avoidance, minimization, restoration, and offset efforts within the conservation hierarchy, because aerial views and specific biodiversity data can help identify where to avoid or limit development, which areas need restoration, and monitor progress towards such goals. On top of their efficiency in obtaining the detailed information, these technologies do so without causing disturbance to the ecosystem of study.

One form of remote sensing is Light Detection and Ranging – LiDAR, which takes light from a pulsed beam and measures ranges to Earth, allowing for observers to gain a 3D image of the targeted area. It differs from satellite or aerial captures as it is an active remote sensing method that emits light and thereby can provide more structural data, i.e., data that can more easily be processed in a database. LiDAR has widespread ecological application, but perhaps works best for forestry as it provides a detailed description of the composition of a forest and canopy[28].

Satellites and Unmanned Aerial Vehicles (UAVs) are other forms of remote sensing and mapping IoT technology. UAVs, commonly referred to as drones, provide an aerial view from as far or close to the subject as necessary and practical, thereby, as the Nature Conservancy puts it "maximizing information received while minimizing disturbance"[29]. Satellites also provide images without disturbance, but from a fixed location in space, and if necessary, of a very large area. Satellites and UAVs can capture the same parcel of land over time, comparing the images, and note any discrepancies that might reveal increased or decreased biodiversity. An example of this is using UAVs to detect chimpanzee nests in Tanzania. Using drones, researchers from several universities and the Jane Goodall Institute were able to remotely discover these notoriously elusive animals as well as their nets and map their location to promote the protection and conservation of this land area all while minimizing human disturbance[30].

Figure 9. Drone flying over Colorado landscape.

Low-cost sensors

There is a plethora of different low-cost sensors available these days that can be employed in settings ranging from forest to farm to buildings. In buildings, motion detectors, thermometers, and flow rate sensors are used for operation optimizations through room occupancy detection, auto-climate adjustments, energy-saving ambient lighting, thermal imaging, air quality detection and water leak detection. In an agricultural setting, things like nitrogen and pressure sensors can monitor local soil and weather conditions. And when deployed in ecosystem setting, sound and movement sensors can assist in conservation efforts.

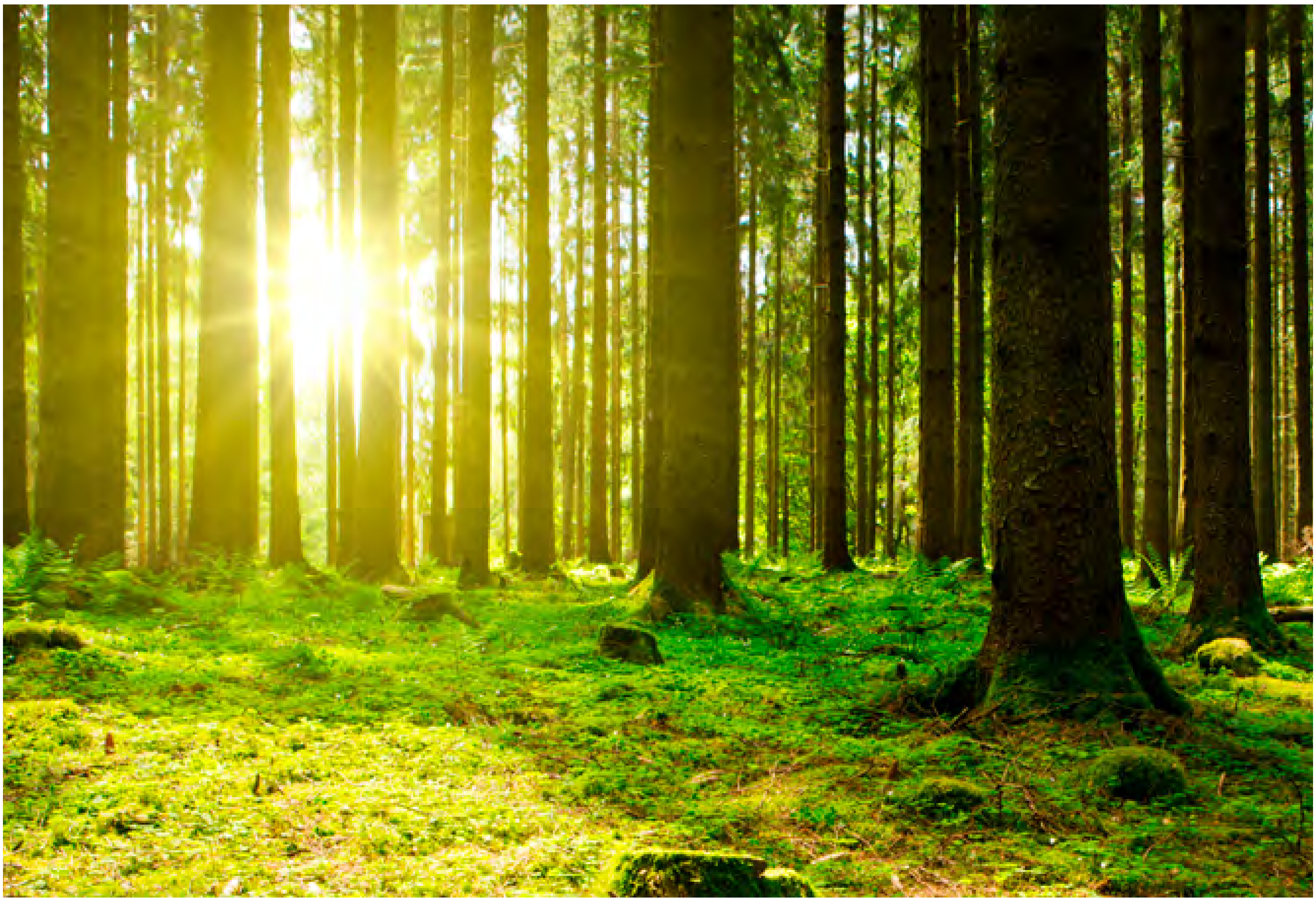
(27) IBM (2023b)
(28) Remote Sensing Biodiversity (2017)
(29) The Nature Conservancy (n.d.)
(30) Bonnin, N. et al. (2018)

IoT can be a major asset in instating nature-positive business practices. In the nature-positive economy, where resources and materials have an elongated lifespan, IoT serves as a way of monitoring and reporting the conditions and variables of these assets. So-called "green homes", for example, use IoT to reduce energy and water consumption, monitor materials, and track carbon emissions. Such tech-enabled homes release 13% less carbon emissions on average[31], and according to major real estate corporations, enjoy a sale price premium of up to 7.6%[32]. An example of a small non-Western company promoting environmental change through IoT is the Taiwanese social enterprise DOMI[33]. DOMI uses various energy saving techniques, which work through efficiency as well as behavioral change through feedback, all enabled by IoT devices.

Another example is in the growing practice of regenerative agriculture, in which the production system restores the soil, leading to increased carbon drawdown, water cycle improvements and long-term sustainability for farms. Yara is an agronomic company utilizing IoT devices to optimize the implementation of regenerative agriculture. Yara implements several variations of IoT, including nitrogen sensors, satellite imagery and growth monitoring devices, all of which assist farmers in ensuring the health of the soil and quality of their crops[34]. IoT within regenerative agriculture is already a well-established idea, with projections stating the global market for IoT in agriculture will reach $30.8 billion USD by 2025[35].

IoT also enables ways to avoid, minimize, restore and offset biodiversity loss in line with the conservation hierarchy through remote monitoring capabilities. One of conservation's greatest challenges is an inability for well-intentioned companies or advocates to be physically present for many of the major causes of biodiversity loss. But IoT sensors can detect movements or changes in the environment that could indicate a destructive or polluting action, and relay this to corporate leadership, authorities, or supervisors. IoT has been instituted in this way to combat illegal logging in the world's first "Smart Forest", for example. Romania, in partnership with Vodafone and Rainbow Connection, has equipped one of its forests, the Zabala, with acoustic. Smart sensors that can detect the sounds of logging and alert park rangers in real time so that intervention can occur immediately, avoiding much damage[36]. IoT has also been used in supply chain mapping, one of the new frontiers in corporate biodiversity action, as a method of impact minimization along the chain by tracking where resources originate from. To come back to the Unilever example, next to using the GreenToken blockchain, Unilever also partnered with satellite imagery and data analytics firm Orbital Insight to track the supply chain of palm oil products using IoT[37].

Figure 10. Using IoT to help forests from monitoring the conditions to combat illegal logging.



(31) Cordell, J (2023)
(32) Margalit, D. (2023)
(33) 認識我們|DOMI綠然 (n.d.)
(34) Yara (2023)
(35) Rana, D. (2023)
(36) Vodaphone (2021)
(37) Unilever (2023)

The Internet of People, The World Wide Web

Although a much more established technology than the aforementioned ones, the World Wide Web, here referred to as the "Internet of People" is worth mentioning as a digital solution in the biodiversity context too. As we all know, the internet is a transformative technology through its capability to connect people, enabling things like joining forces on data collection, information sharing, educating oneself and one another, and organized mobilization online and offline. This capability can prove useful to biodiversity too.

Education and mobilization

Short informational videos, full-blown online courses, informative memes, or months-long online campaigns can raise awareness, grow interests, and gain momentum for many causes, including for biodiversity ones. Such online information sharing and education can contribute to support for nature-positive products, for example, and the most impactful ways individuals or corporations can achieve all aspects of the conservation hierarchy, including the avoidance level of consuming less. Social media in particular has been used for mobilization purposes, such as online signature campaigns or promoting offline events.

An example is the online content sharing platform Impact and its climate focused subsect Environment. Environment shares daily relevant environmental news to its 812,000 Instagram followers. These news blurbs, that are about anything from fast fashion brands you should avoid to the causes of the Canadian wildfires, deliver quick, informative, and well-designed infographics that users can then like, comment, or share to their own Instagram profile. This delivery method allows for people to engage in important discussions and gain a quick education on ways to minimize their contribution to biodiversity degradation, such as how to consume less or find the products options with the least impact[38].

Figure 11. World map with people of diverse cultures talking over network.

Data collection and sharing

Another significant contribution of the internet is the co-creation of vast, shareable databases by multiple parties. One particularly notable example of this in the biodiversity context is citizen data sharing: apps available to everyday people allow them to add to databases on biodiversity. These so-called "citizen scientists" can thereby add valuable complementing data to that collected through eDNA and IoT, for instance. Database sharing and connectivity allow for a broader, more complete understanding of many of the problems facing global biodiversity, which in turn create the most appropriate solution. This is particularly significant in the conservation hierarchy as more data will lead to more informed decisions of how or where to avoid, minimize, restore, or offset biodiversity loss.

iNaturalist, for example, is a social network web platform and app that allows anyone to share information on biodiversity from anywhere in the world. iNaturalist currently has over 160 million observations of biodiversity, which are valuable additions to future biodiversity movements and strengthens the insights people can make about biodiversity trends in parts of the world that are either less studied or less emphasized. It adds to a holistic view of the planet's biodiversity which can inform ways to participate in the conservation hierarchy[39].

Another example of shared database co-creation is the Digital Extended Specimens, a network of digital databases that links specimen data to relevant ecological, environmental, and conservation data. Biodiversity databases already exist on a smaller and isolated scale, but this aggregator platform connects these many databases and also works with machine algorithms, thus enhancing understanding of and interdisciplinary collaboration on biodiversity across the globe[40].

Figure 12. Citizen observers.

(38) Impact (2023)
(39) iNaturalist (n.d.)
(40) Hardisty, A. et al (2022)

2 Implementing the technologies effectively and purposefully

As the examples have illustrated, the various technologies hold promise for different areas in biodiversity action. The overview given in the previous section is distilled in a table below, showing the potential for each individual technology both in terms of conservation and strategic business opportunity. Furthermore, although these technologies are all beneficial and effective on their own, their impact can be maximized when used in conjunction with other digital technologies, human assistance, and when placed in the larger economic and policy context. Each of these areas are discussed further in this section.

Potential of individual technologies

Table 1 shows an assessment of each technology against the different areas in biodiversity action, expressed in a rating of either low, medium, or high. This assessment is based on practices as they are emerging or existing today and does not preclude entirely new applications to change a potential from low to medium or high in the future.

The ratings can be interpreted as the extent to which the key contributions that each technology offers can bolster the kind of actions that fall in the specific level of the conservation hierarchy or creation of nature-positive products and services. For example, biodiversity credits can suffer from a lack of trust from potential buyers, something which blockchain can provide. Offsets often happen at different location than where the damage to biodiversity was done, which is where remote-sensing IoT devices pose a solution. AI's key contribution of highly efficient analysis of large datasets can make subsequent biodiversity action much better targeted and add further trust through verification of claimed conservation and restoration results. All three of these technologies thus offer a high potential for offsets.

Table 1. Linking digital solutions to the conservation hierarchy and nature-positive business potential.

Technology		AI	Blockchain	eDNA	IoT	Internet of People
	Nature-positive business	high	high	low	high	medium
Hierarchy	**Avoid**	high	low	high	high	high
	Minimize	high	high	high	high	high
	Restore	high	high	low	high	medium
	Offset	high	high	medium	high	medium

AI's capability to analyze vast datasets offers high potential for each level of the conservation hierarchy because the data that is fed into the algorithms can be relevant for avoidance, minimization, restoration, and/or offsetting. Because AI can significantly reduce pollution generation and resource consumption, as well as support restorative and profitable activities like regenerative agriculture, especially when combined with other technologies like blockchain and IoT (see next section) its nature-positive business potential is rated high.

Blockchain offers high potential for all levels of the conservation hierarchy except avoid, because it can add trust and transparency to each of these levels. Avoid has been marked "low" because true avoidance would mean there is no product to track on the blockchain. In similar reasoning as for AI, blockchain has high nature-positive business potential because it has demonstrated potential to reduce material use, and promising, albeit emerging, use in regenerative agriculture practices.

eDNA is only applicable to conservation today. It's ability to detect species in need of protection give it value in avoidance and minimization of loss, but it cannot truly contribute to the nature-positive business model, nor can it provide much help in restoration processes. Because most offsetting projects are either of the avoidance (high potential for this technology) or restoration (low potential for this technology) kind, the offsetting potential for eDNA has been rated as medium.

IoT improves efficiency and breadth of data collection, which can optimize approaches to confirm the complete avoidance, minimization, or restoration of impacts. Avoidance and restoration can be tracked either at the location of impacts or somewhere else, which in the latter case would constitute offsetting, making its potential high for this last level of conservation. IoT's ability to improve data collection can sometimes be sellable, giving it a high potential for nature-positive products and services too.

The **Internet of People**'s knowledge-sharing capability provides high potential for avoiding and minimizing biodiversity impacts, especially through shared research databases. These databases seem to have not yet been applied to the offset or restoration level. The marketing of nature-positive products, ability to learn how you can offset or restore your own damage, lie in the individual consumer sphere, which has its limits in terms of systemic impact. So the potential for nature-positive business, restoration, and offsets has been rated as medium.

Combination of digital technologies for better results

Although each individually productive, the aforementioned technologies demonstrate significant synergy when put together and optimizes each one's functionality. Generally, IoT collects and stores data, blockchain provides security in infrastructure and laws of engagement, AI optimizes these processes, and the internet provides public access to the results of these. The individual tasks of these technologies are often reliant on others. For example, the information and data captured by IoT sensors are processed by AI using databases found on the Internet, and could certainly include eDNA when relevant. These results are then synthesized, and perhaps sent on the private blockchain, where eventually the results could be shared and reviewed by the public on the internet.

Generally, there are several repetitious and laborious tasks in the first steps of biodiversity projects, which could benefit from the technologies discussed in this paper. When these technologies are used collaboratively as described above, the human component of these projects is reached much faster, more accurately, and at much larger scale. Perhaps the best example of this is the combination of AI and IoT. IoT produces a plethora of data and AI can analyze and assess that data and compute it into a product or result that can be used for meaningful insights. IoT sensors can record and transcribe the various data it encounters while AI can utilize its programming to identify and track patterns at a scale and pace that human beings simply could never achieve. As one conservation specialist put it after a successful pilot of a combination of robot monitors and AI analysis at wildlife sites in the United Kingdom: "We couldn't have done it at that scale using human observers"[41].

The previously mentioned Yara is an example of a nature-positive company using this powerful combination, as it used not just IoT devices but also AI to optimize its regenerative agriculture business. The Costa Rican company Indigo Drones also uses the IoT and AI combination to bring "precision agriculture" to small farmers, helping them to cut back significantly on water and pesticide use[42]. Another example of a nature-positive company using this combination is the water intelligence company WINT. WINT utilizes AI and IoT devices to alert users of water leaks and offer the ability to shut down the system when a leak is detected. The technology has pattern recognition and sensors to locate leaks, and through AI's learning ability, overtime adapts to occupants' water usage. The Empire State Realty Trust implemented WINT technology in the Empire State Building and saved 7.5 million gallons per year and over $100,000 USD, helping achieve its sustainability goals and preventing potential leak damage[43, 44].

Rebalance Earth[45] is an example of an organization that uses a combination of AI, blockchain and IoT for corporate biodiversity action. Businesses looking to offset their carbon contributions can purchase so-called "Eco-Tokens", generated by private blockchain, which quantify the environmental additions keystone species, such as the forest elephant, provide. IoT sensors and AI data sets are used to track the amount of carbon sequestration these elephants produce.

Combination of digital technologies and human beings for best results

Programs such as AI have been propositioned as being contrary to human labor, when the two are distinctly complimentary if utilized well. Automation is an incredibly worthwhile tool when used collaboratively with human insight but falls short when used solely on its own. At its best, technology takes over highly laborious tasks previously done by humans and expedites many iterations of a dull, but necessary step. When technology eliminates the human limits of boredom and comparatively benign stamina, we benefit from that. But technology lacks the human characteristics of creativity, curiosity, and truly new insight-generation. Thus, when used collaboratively, humans and technology can utilize their respective strengths to produce the best results. This idea of technology and human collaboration is already successfully playing out across the biodiversity field.

An example of how digital technologies and humans work optimally together is the partnership between information technology service group Accenture's R&D group The Dock and the Australian Institute of Marine Science to protect the coral reefs[46]. Their program combines AI, the internet, and "citizen scientists" by allowing any user to submit photos of the reef which the AI program will then analyze and store in public databases with approximately 90% accuracy. This process is 700 times faster than when done with human labor, which allows for marine scientists to spend far less time sorting through datasets and much more creating and help implement effective policies. In what ReefCloud Director Manuel Gonzalez Rivero calls a "democratization of knowledge" the program allows access to up-to-date reef monitoring information across the world.

Figure 13. Coral Reef.

Another example is the Ingliniit Project[47], which equips Inuit hunters with tracking and monitoring technology to gather data as they go hunting. The resulting interactive map can help with monitoring environmental, wildlife, cultural, and land-use changes. In addition to being another example of how digital technologies and humans can work optimally together, the above cases also show the importance of different human parties working together for the best results. The coral reef example illustrates how the best initiatives often combine a corporate and NGO or research party, whereas the Ingliniit case also illustrates the role of indigenous people as stewards of their lands and the imperative of including them in policy-setting and execution when it comes to biodiversity loss and climate change[48, 49, 50].

(41) McKie (2023)
(42) Indigo Drones (2023)
(43) WINT
(44) Matthews, A. (2022)
(45) Rebalance Earth. (n.d.)
(46) Accenture (2023)
(47) Automated mapping system for the Igliniit (Trails) Project (n.d.)
(48) Sogbanmu et al. (2023)
(49) Goolmeer et al. (2022)
(50) Rundle (2019)

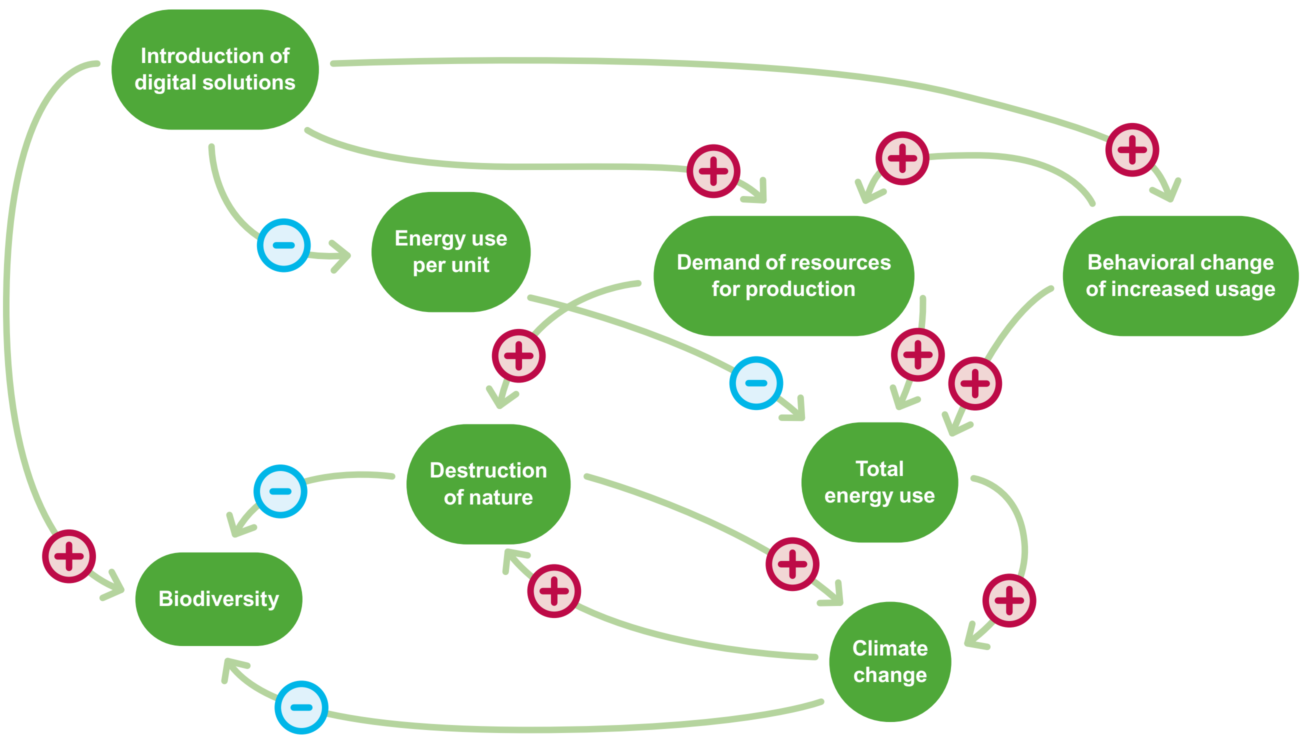
Looking at the system: Possible unintended consequences

Digital solutions are no silver bullet. For one, as mentioned, because they rely on other technologies as well as humans for optimal efficacy. Secondly, the total impact of their application is not automatically positive. The potential of digital technologies to improve conservation efforts and biodiversity restoration will always need to be balanced against potential negative impacts, in this context namely from energy and material resource use. Production and subsequent use, including data storage and connection to the cloud, require materials and energy. Resource exploitation, including mining for minerals and metals – materials necessary to build many technological devices – is a key driver of biodiversity loss. Producing the extra required energy with fossil resources would contribute to climate change, another key driver of biodiversity loss. Bitcoin, perhaps the most notorious use of public blockchain, requires over 150 terawatt hours of electricity annually[51]. That is more electricity than the country of Norway uses in a year, and very little of that is sourced through renewable means. The expansion of AI analysis and data centers has also been significantly driving up energy consumption on a global scale, and is estimated to be responsible for more than 3.5% of total global electricity demand by 2030[52].

There are also potential negative impacts stemming from behavioral changes around what by themselves are green solutions, and green digital solutions for biodiversity are not exempt from the possibility of ending in a so-called Jevons' Paradox. Jevons' Paradox states that when use of a finite resource becomes more efficient, total consumption of that resource rises rather than falls. The reason is behavioral change: Because the resource becomes more accessible and affordable through the efficiency increase, it is more widely sought out. An example of this in the context of biodiversity is the use of UAV's. By themselves, UAVs are a low energy method of surveillance. But, as demand increases due to the promise they hold, the resulting increase in production inevitably leads to an increase in a new source of energy and materials consumption.[53] What was once an energy efficient means of surveillance has now a larger total energy footprint. This does not mean that the use of UAV's is always bad, of course. It does mean that a proper project assessment should include this increased footprint, so it can be weighed against other positive impacts, such as, hopefully, replacement of other surveillance techniques even higher in resource use, or an improvement in biodiversity that justifies the energy and resource impacts.

The above interactions are depicted in the causal loop diagram below. The left arrow down from the Introduction of the digital solution represents the direct positive potential of the technology's application for biodiversity. The total of arrows on the right-side form the negative and unintended consequences, including Jevon's paradox ("behavioral change of increased usage"). The relative strength of the different connections is what determines whether the digital solution on balance has a positive or negative impact, which will have to be comprehensively assessed on a case-by-case basis.

Figure 14. Causal loop diagram depicting interactions around introduction of digital solutions. The relative strength of the different connections is what determines if the digital solution on balance has a positive or negative impact on biodiversity. By Gaya Herrington.



In general, the abovementioned possible consequences mean that digital solutions for biodiversity action will need to be implemented only when there is a real, significant benefit to the project, even when the possible environmental impacts and behavioral changes are considered in the benefit analysis. Using renewable energy for the digital technologies, when possible, would make this the case more often.

(51) Hinsdale, J. (2022)
(52) Stokel-Walker. (2023)
(53) Bertran, E. & Sanchez-Cerda, A. (2016)

Looking at the system: Conducive policies, local community, and the economy

For optimal results in biodiversity action, an organization takes the policy frameworks and overall societal system – the local community and economy – into account as well.

Examples of government frameworks or incentives that work to promote biodiversity include establishing protected areas, green taxation, or Payments for Ecosystems Services (PES)[54]. Conservation of biodiversity is clearly shaped by such government policies, but the business environment for nature-positive technological solutions also depends heavily on the availability of the right economic incentives. For example, in the most densely biodiverse country in the world, Costa Rica, farmers are not just taking up digital technologies like the UAVs and AI capabilities that companies like the earlier-mentioned Indigo Drones sells. The country is also known for its PES programs in which landowners are paid for the ecological services their lands produce when practicing sustainable land use and forest-management techniques. This way, these small farms generate profit capable of sustaining the businesses of the by now more than 18,000 Costa Rican family farms[55].

The really smart organizations aren't just using IoT devices, they understand that they can only thrive long-term if their local community thrives, including economically. Larger corporations may choose to work with NGOs to make this community connection. The earlier mentioned Rebalance Earth works as such a bridge, and it's why it focusses on more than just biodiversity, with its stated purpose of "contributing to the local green economy". Rebalance Earth shares the income from the Eco Tokens they sell to corporations with the rangers and community members[56]. This approach makes sense, as it provides an incentive for the community to protect the keystone species by fusing their economic success with the success of biodiversity action. Smaller companies can capitalize on societal and environmental synergy more directly. The earlier mentioned social enterprise DOMI does not just work on environmental change, but rather couples this with social justice: with its IoT enabled energy saving solutions, DOMI aims to lower energy costs for energy poor households[57]. Next to achieving carbon emission reductions, with this inclusionary approach the company also ensures itself of a growing customers base.

In short, the entrepreneurship of the people behind these and many more nature-positive and social businesses notwithstanding, their success rests on support from their government and the local community they operate within. When human parties, including the business, NGO and government sector, work together with one another and available technologies, environmental stewardship can form the bridge between economic, biodiversity, and social optimization[58].

Figure 15. Costa Rican jungle.

(54) de Lange, E. et al (2023)
(55) United Nations Climate Change (n.d.)
(56) INDUSTRIA (2022)
(57) 認識我們|DOMI綠然 (n.d.)
(58) Heller, N.E. et al. (2023)

Conclusion

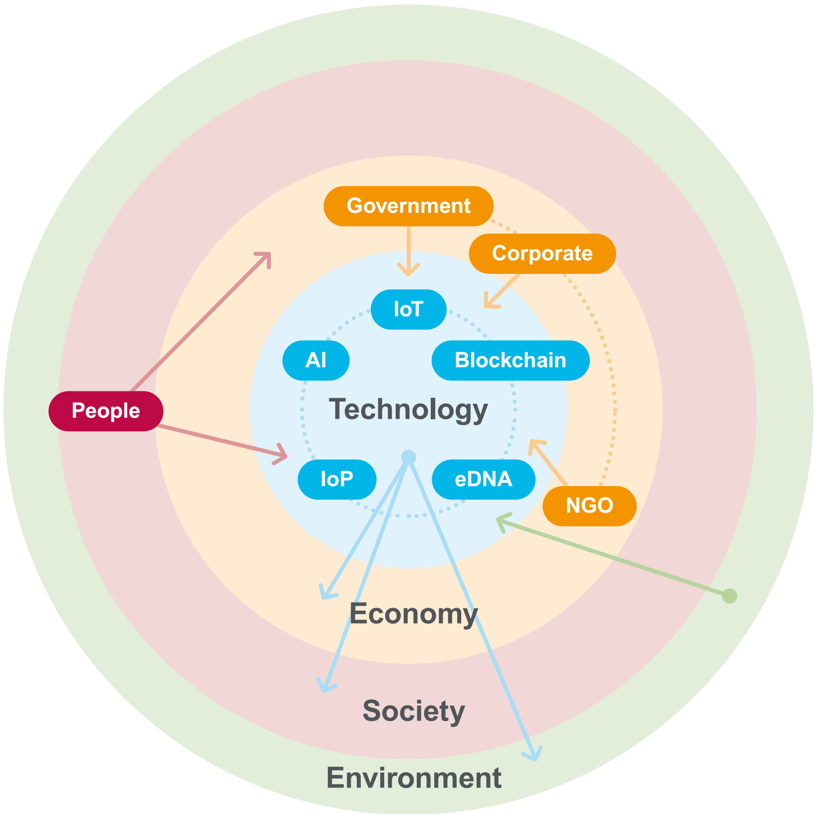
This paper provided an overview of modern or emerging digital technologies, put in the context of corporate biodiversity action, in hopes of supporting such efforts with concrete and actionable information. We discussed the basic workings and potential of AI, Blockchain Technology, eDNA, IoT, and the World Wide Web. AI greatly enhances speed, scale, and detail with which biodiversity datasets can be analyzed. With its encryption capabilities, blockchain provides security and enhances trust in biodiversity data. eDNA enables biodiversity data collection in remote or harsh environments in much more effective and less intrusive ways than previously possible. IoT makes collection and storage of a plethora of environmental data either newly possible or radically more efficient. And the internet facilitates people enhancing these datasets with complementary data, broadens access to those datasets for analysis, and allows public access to the human insights and proposed actions that result at the end of this research process.

Based on applications today, AI offers high potential for nature-positive business opportunities and every level of the conservation hierarchy. Blockchain and IoT show much promise in both business potential and conservation too. eDNA and the internet skew more towards biodiversity conservation in terms of their potential, rating high for several, although not all, levels of the hierarchy. We further laid out how these technologies often work best in combination, as ultimately, these technologies offer complementary ways of optimizing how we use data for optimally targeted biodiversity action. Simply put: AI can distill the vast amounts of data collected with IoT, eDNA, and people down to relevant information, securely transferred using a private blockchain, and accessed by everyone who wants to use it for research and analysis it in real-time over the internet.

Their enormous potential for biodiversity action and beyond notwithstanding, these digital solutions were not presented as to always be a sufficient solution by themselves. If our current environmental crises, like biodiversity loss but also climate change or rising water scarcity, could be solved with just technological solutions, they would have been so by now. Truly effective digital solutions are deployed with human complementary capabilities and behavioral impacts, either positive or negative, in mind. Technologies are supposed to support humans' strengths, including their ability to come up with truly new insights. Additionally, unintended consequences can arise because of an increase in the use of the digital solution, as demonstrated by Jevons' Paradox. This kind of behavioral impact should be included in any benefit analysis of the application of the technology in biodiversity action.

Lastly, digital solutions should be deployed with the overall economic and societal system in mind. Corporations will find (and often already have found) that working together with an NGO, the local community, and when relevant indigenous people, will bring the most impact for corporate biodiversity action. This is especially true when operating within biodiversity-supporting government policies and frameworks. As illustrated by the many examples in this paper, from startup to multinational companies, this holds not just for biodiversity conservation, but also in finding profitable markets for nature-positive products and services enabled by these digital technologies. Guided by environmental stewardship from humans working together, these digital solutions hold immense potential to launch the bending of the biodiversity curve this decade needs.

Figure 16. Tech and the players in the technological, economic, societal, and environmental systems. Dotted lines indicate the connected entities working together, the arrows indicate input or benefits delivered. Visualizes how optimal combination of digital technologies in the inner circle (the technology sector) supported with the right government policies, and deployed with collaboration between individuals, local community, companies, and/or NGOs in the larger economy (the second inner circle), delivers value, including biodiversity preservation and restoration, for the outer two circles (society and nature).



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