Discussion paper:

5 March 2019

The Case for a Digital Ecosystem for the Environment:

Bringing together data, algorithms and insights for sustainable development

UN environment assembly

The Fourth United Nations Environment Assembly of the United Nations Environment Programme

THINK BEYOND

LIVE WITHIN

SCIENCE POLICY BUSINESS FORUM

Bandura 2018

ABSTRACT

The planet is not currently on a sustainable path. In order to change the current trajectory requires transparency, inclusion and accountability. A shift in the global political economy of environmental data is needed to harness the efforts of public and private sectors to jointly generate high quality data and insights as a global public good while avoiding technology and data monopolies. The global economy is changing and we will not be able to achieve the environmental SDGs or environmental sustainability without utilizing frontier technologies and integrated data. Social media networks are shaping consumer preferences and political outcomes across the globe. There is still an opportunity to change the current trajectory if we use data and information: to build awareness of the state of our planet, to influence consumer behaviour, to inform markets and to reform governance systems.

A global digital ecosystem for the environment has the potential to put us on a path toward a sustainable future. This will require action from citizens, governments, the private sector and intergovernmental organisations to collect and share data, process data and create analytical insights and information. Citizens must be engaged in using and collecting data. Countries must create a culture of data use, innovation and data governance for national data ecosystems. A private sector contribution related the sharing of data, algorithms and expertise is key. The UN can play a role to incubate and develop a global digital ecosystem which is built upon innovative partnerships across stakeholders. As the global entity responsible for the environment, UN Environment is responsible for leadership in developing an approach to govern the digital ecosystem for the environment as part of a broader sustainable development ecosystem and to bring existing environment related data into focus for policy making. This will be done through envisioning the role of different stakeholders in a digital ecosystem and through making data and information more accessible including through the Environment Situation Room and the MapX spatial data platform of UN Environment.

PART 1:

High Level Summary, Conclusions and Recommendation

1. BACKGROUND AND OBJECTIVES

This discussion paper outlines the status quo of the most salient challenges related to the collection, management and use of environmental data, algorithms and insights according to a comprehensive group of international stakeholders convened by UN Environment and the UN Science Policy Business Forum (see Annex I). The paper translates a summary of various priorities and inputs into a consolidated vision statement and set of opportunities, risks and governance challenges. It calls for the establishment of a digital ecosystem for the environment as a global public good, governed through an international process backed by the UN as a key tool to monitor the health of our planet and the achievement of the Sustainable Development Goals.

This paper has been developed through a consultative process led by UN Environment through the UN Science-Policy-Business Forum.[1] It is based on more than a year of consultations with public and private stakeholders from all sectors (see Annex I) together with a thorough review of various environmental data platforms and proposals (Annex II). The objective of the consultation was to initiate work towards identifying the underlying conditions necessary to establish a collective vision for a global digital ecosystem of environmental data, algorithms and insights that can provide actionable information for achieving the environmental dimensions of sustainable development. This paper reflects the views expressed by the diverse mix of stakeholders who engaged in the process and should be treated as a work in progress.

The paper does not serve as a road map for implementation of this vision but instead provides a catalogue of key principles and proposed foundational elements including the data, infrastructure, the content and the application of any future platform or system of platforms and possible paths towards financing this vision. The primary intent of the paper is to define the required level of ambition for a future digital ecosystem for the environment, uncompromised by practical constraints, but fully cognizant that the implementation of this vision will be gradual. In this way, the paper serves as a basis to rally stakeholders from the public and private sector, as well as individual global citizens, who share the same vision, objectives and values and invites them to become the architects of the proposed digital ecosystem for the environment.

Following the launch of the paper at the UN Environmental Assembly, additional feedback from policy makers and stakeholders will be sought. On this basis, the UN Science Policy Business Forum will then act as the primary incubator for the practical implementation strategy to gradually translate this vision into a reality. The Forum will create numerous opportunities to collect stakeholder feedback on the emerging strategy. To provide your views on the vision outlined in this paper and learn more about how you can contribute to its implementation, please contact the Secretariat of the UN Science Policy Business Forum.

2. WHY WE NEED A DIGITAL ECOSYSTEM FOR THE ENVIRONMENT

Data have tremendous potential to be used as powerful resources for good. However, this will only happen if governments, the private sector, academics, citizens and other stakeholders work together to match policy needs, data streams, technological solutions and technical expertise. It is time for stakeholders in all domains to unite in building an open digital ecosystem of data, algorithms and insights in order to provide actionable evidence on the state of the environment and interactions between the economy, society and the environment. Actionable evidence must be easily understood by decision-makers, investors, consumers and citizens alike to maximise participation, accountability and market pressure. While many digital initiatives are proliferating around the environment and the sustainable use of natural resources, their coordination, proposed interventions and calls for action could be improved, better targeted and more directly linked to the Sustainable Development Goals (SDGs).

A digital ecosystem can be defined as 'a complex distributed network or interconnected socio-technological system' with adaptive properties of self-organization and scalability. In this sense a digital ecosystem much like natural ecosystems are characterized by competition and collaboration among its many diverse components. It is the interactions and linkages between these seemingly individual or autonomous entities that make an ecosystem functional. A digital ecosystem for the environment must connect individual data sets with algorithms and analysis in order to create insights. Additionally, a digital ecosystem will require a well-designed infrastructure to facilitate data exchange, processing and visualization. This ecosystem must also leverage open data exchange between the public and

1) This paper was co-authored by David Jensen (Head of Environmental Peacebuilding Programme and Co-director of the MapX platform for spatial environmental data) and Jillian Campbell (Chief Statistician) of UN Environment. Additional inputs from UN Environment were provided by Shereen Zorba, Alex Caldas, Pascal Peduzzi, Saiful Ridwan, Ben Simmons, Andrew Morton, Inga Petersen, Jason Jabbour, Barbara Hendrie, Shereen Zorba, and Rachel Kosse. It was mandated by the working group on Data, Analytics and AI of the UN Science-Policy-Business Forum, by the UN Environment Chief Scientist, Mr. Jian Liu and by the Director of the Division Policy and Planning, Mr. Gary Lewis. The paper reflects the inputs and feedback provided by the stakeholder consultation process listed in Annex I.

private sector, it must offer protections for data privacy and security, and it must include safeguards for data quality.

As natural resources and ecosystem services are under growing pressure from environmental degradation, population growth and climate change, there is an increasing potential for global and local economic and social instability. These threats also directly impact people as they create challenges in terms of declining food and water security, increasing threats to human health from air, water and soil pollution and pronounced inequality in terms of access to natural resources. When these environmental challenges are coupled with the anticipated changes in labour market demand that are likely to result from growth in artificial intelligence, robotic automation and other technologies, the human population is facing unprecedented challenges. These challenges can and will create localised conflict, environmental migration and other environmental security risks. On the other hand, by using new technologies to better understand challenges and threats to create targeted interventions and actions, there is a path to a more sustainable, inclusive and peaceful future. Additionally, there are opportunities to create green products and interventions that have economic value in addition to value in improving resilience and reducing vulnerability.

Frontier technology is being increasingly used to generate data, process them for transformation into information, ready to conduct analysis and dissemination. For example, satellite data is being integrated with other sources of data to map ecosystem extent; the Global Biodiversity Information Facility provides free and open access to more than 1 billion individual records, mostly from citizen scientists on where and when species have been observed or collected; and there are many efforts to pull data together from different sources (more examples are included in Annex II). However, there are still many gaps in terms of creating global time series data which can be used to measure the planet's most pressing issues (roughly 30% of the environmental SDG indicators still do not have an agreed methodology) (United Nations [UN] 2018a).

Countries and companies are increasingly interested in mapping natural resources together with social and environmental trends, but often with competing objectives and uneven access to technology. On the one hand governments are responsible for working toward the achievement of the social, economic and environmental objectives of the Sustainable Development Goals (SDGs), but often lack access to data, technological capacity and human resources for analysing the interactions and trade-offs between the different aspects of sustainable development. On the other hand, companies often possess technological and human capacity, but lack incentives for contributing directly to the SDGs. In many cases, they are using technologies to promote and accelerate unsustainable consumption and production practices.

A common vision toward building and governing an open digital ecosystem of environmental data, analytical algorithms and policy insights is vital to guarantee the sustainable use of natural resources and targeted actions to ensure the future of our planet. Such an ecosystem must have a clear value-added business case and must provide transparent, open access to aggregated data while ensuring the protection of privacy and confidentiality. The ecosystem must be interoperable with social and economic data that would require factoring in norms, standards, frequencies and territory definitions that are already used in those sectors. Additionally, methodologies, algorithms and quality assurance information should be part of the ecosystem. Creating new real-time and time series data products, statistics and indicators is not enough. This information must be transformed into actionable insights that can be easily digested by decision-makers, investors, consumers and citizens. An effective digital ecosystem would not be stagnant, but would regularly seek input users and proactively "scouting" new relevant technologies and use cases.

A digital ecosystem for the environment would offer an improved ability to make informed decisions and evaluate policy interventions based on trustworthy information about the state of the environment and interactions between the economy, society and the environment. For example, real time air quality warnings allow citizens to make decisions on whether to wear an air filtration mask and use public transport or data on the cause of waterbody decline might allow a country to adjust their agricultural policy or better engage in transboundary basin discussions. But how to build, finance and maintain such a global public good and how to harness it as an accountability mechanism for achieving the SDGs opens up a challenging set of questions.

The United Nations can provide global leadership to build a partnership and operationalise an ecosystem of environmental data, algorithms and insights. At the same time, such an initiative needs to promote renewable energy solutions across the data ecosystem, address e-waste management and responsible supply chain sourcing, and establish governance processes, safeguards and value-based guidance for disruptive technologies such as big data, blockchain and artificial intelligence. This ecosystem will be co-built with states and non-states actors to address the needs and create consensus, trust and legitimacy. Such a global partnership could be initiated with interested member states and partners (early adopters) which can be expanded over time. The UN and partners can now work toward a vision and governance framework for such an ecosystem that offers the right mix of incentives, standards and financial models to support innovation, profit making and generation of global public goods. A future that leverages the 4th industrial revolution for the environment is ours to imagine and create.

3. CREATING A DIGITAL ECOSYSTEMFOR THE ENVIRONMENT PARTNERSHIP

A) Financing and development

Humanity now has the potential to leverage a range of new data sources and technical innovations that could help monitor the planet at the global, national and local levels. There have been gains in leveraging new data and technology for the environment, for example through using mobile applications for citizen science, multipurpose environmental sensors collecting real-time data within the internet of things (IoT), or artificial intelligence algorithms to analyse earth observation data and detect patterns of change. However, currently the investment in technologies and data collection has been dominated by private sector investments and short term financial incentives which often tend to promote consumerism and increased consumption rather than sustainability. Currently, a small number of companies and countries control most of the digital infrastructure needed to gather and use global-scale data, together with the expertise and capacity to deploy artificial intelligence for consumer preference monitoring, market trend detection, prediction and business intelligence. If this trend continues, it could further amplify information asymmetries between countries and between the private and public sectors which could potentially undermine the sustainable use and fair contracting of natural resources. This potential scenario calls for action to guarantee data innovation as a global public good together with investments in capacity building to prevent the digital divide from escalating.

Humanity has entered a new world in which knowledge and data are increasingly digital, personalized, networked, algorithmic and becoming privatized. In such a world, old models of the science-policy interface that can drive sustainability are no longer fit for purpose. A people-centred and publicly-powered engine for enabling the world to more collectively share, learn, and act towards the environmental dimensions of the SDGs is needed.

The United Nations can act as a convener and trustworthy global institution to form a partnership toward developing a common vision and financing options for an open ecosystem of environmental data, algorithms and information. The operational and governance challenges for data and algorithms are complex and involve numerous stakeholders. A partnership would also rely on governments, private sector actors, academic institutions and other stakeholders to contribute toward the development of a data ecosystem as a global public good. A global partnership would be a first step toward forging a common path forward that respects the ideals of the UN charter and the SDGs: a vision that unites people, planet, prosperity and peace.

Developing the data ecosystem calls for innovative financing which requires developing business models and strategies to address a few fundamental questions: how to finance the costs of maintaining a global public good, including data acquisition, processing, storage and analysis; who should have access to what level of data for what purpose; how can cloud computing costs be offset or subsidised to lessen the digital divide between countries and how can the infrastructure be globally distributed? The technology and data science sector add tremendous value to the global economy which have the potential to increase government revenue for the environment and for improved environmental monitoring.

The data within the ecosystem will include a range of private and public sector data. Governments, intergovernmental organisations, academic institutions and non-governmental organisations play a large role in stimulating data collection and data sharing; however, data is often not open and is not coupled with the technological expertise or processing power needed to generate trusted insights at any scale.

To address the issue of data sharing, there is a need to identify opportunities to ensure that public funds which finance private data collection have conditions on data release and disclosure in the appropriate format. Commercially sensitive data can either be held back, anonymised, or aggregated but we must make data sharing a new norm in the social licence of business to operate. The formation of a digital ecosystem of data, algorithms and insights would also serve as a mechanism for identifying gaps in understanding which natural resource data sets are needed and gaps in publicly funded data collection.

Data access and sharing are still the most important barriers in terms of building an international public data ecosystem. Data sharing is more of a challenge than the application of technologies needed for processing and extracting insights (e.g. the technologies exist at low cost but need the data). Even within public institutions and academia, many data sets are not actively released or come with non-commercial use restrictions. Open source software is a viable, secure and low-cost solution that can be adopted by all stakeholders to access data and monitor changes in natural resources and the environment. Open source solutions allow data to flow freely among ecosystems and promote inter-operability. However, data integration and the implementation of open source solutions still have financing needs. Using data for societally-robust results is best achieved through collaboration which utilizes open source software, where efforts and costs of software development and maintenance can be shared between private and public partners. In order to achieve this financing method, agreed-upon principles must be established to guide the common package of open source software.

B) Governing principles

Open data, open algorithms, transparency and safeguarding of privacy must be at the core of an ecosystem for data, algorithms and insights. An ecosystem for data, algorithms and insights does not live in a single cloud – but as a network where data, data processing techniques, metadata and experiences can be shared, tracked and replicated by an open community. Ensuring transparency and using only trusted data sources will be increasingly important in a world where social media posts, written narratives, images, videos and in the future perhaps even consciousness can be created and altered.

A successful global strategy should be forward looking to bring in new data sources, promote new data collection, use frontier technologies and be adaptive to future data and technological developments. The ability to garner action relies on the ability to merge the information available with the insights needed to create trusted and actionable information which addresses both risks and negative trends as well as opportunities and positive solutions. Solutions must be targeted toward the most pressing problems and offer opportunities for scaling and global adoption.

A global ecosystem for data, algorithms and insights must foster national engagement and buy-in for data to be used for SDG implementation, policy development and evidence-based behaviours. This requires building capacity of governments, academics and citizens in using and guiding data collection and analysis. A global ecosystem must be fit-for-purpose and provide information to stakeholders who are able to develop data-driven interventions, investments and actions. The global ecosystem would aim to reduce the current concentration of data and technology in a limited number of countries (see Table 1) in order to promote broader use of data and new technologies for development and for data democratisation.[2] This may require a new approach to antitrust rules on data, especially over natural resources and global environmental data.

Table 1: Geographic Concentration of Technology Companies

COMPANY	COUNTRY	VALUE ($B)
Apple	US	915
Amazon	US	828
Alphabet	US	781
Microsoft	US	771
Facebook	US	556
Alibaba	China	484
Tencent	China	477
Netflix	US	173
Ant Financial	China	150
Salesforce	US	102
Bookings Holdings	US	100
Paypal	US	100
Baidu	China	89
Uber	US	72
JD.com	China	56
Didi Chuxing	China	56
Xiaomi	China	54
eBay	US	37
Airbnb	US	31
Meituan-Dianping	China	30

The largest 20 tech giants are listed using market caps for all public companies (Desjardins 2018).

A new social contract between companies, governments and citizens is also required where mutual obligations and responsibilities are spelled out. The cost of doing business anywhere in the world should be the release of relevant non -commercial data into the global data ecosystem that can be used to measure SDG progress. While protection of commercially sensitive and strategic data is important – it is now possible to extract a subset of this information that can contribute to a global public good in terms of a digital ecosystem for the environment. Data provenance[3] is an important investment to support the quality and

2) Data democratisation is a principle that suggests data should be available to everyone in a given organization or system, not just key specialists or leaders (Techopedia 2019).

3) A record showing the origin of data including why and how the data is included (Gupta 2009).

accountability of the data ecosystem. This includes data attribution[4], licensing[5], digital object identifiers (DOI)[6], decentralised identifiers (DIDs)[7], token binding[8], meta data[9], etc. Recognising the origin of data, licensing to acknowledge intellectual property rights, metadata to provide information about other data, and various means of identifying and securing the data are fundamental requirements of a digital ecosystem for the environment to ensure trust, quality and accountability (Saboor 2013). While the collection of data can be benefit from improved sharing of information, data processing and infrastructure at the national level will still require investment and would likely require public funding – thus data sharing alone will not alleviate the need for investing in national statistical systems.

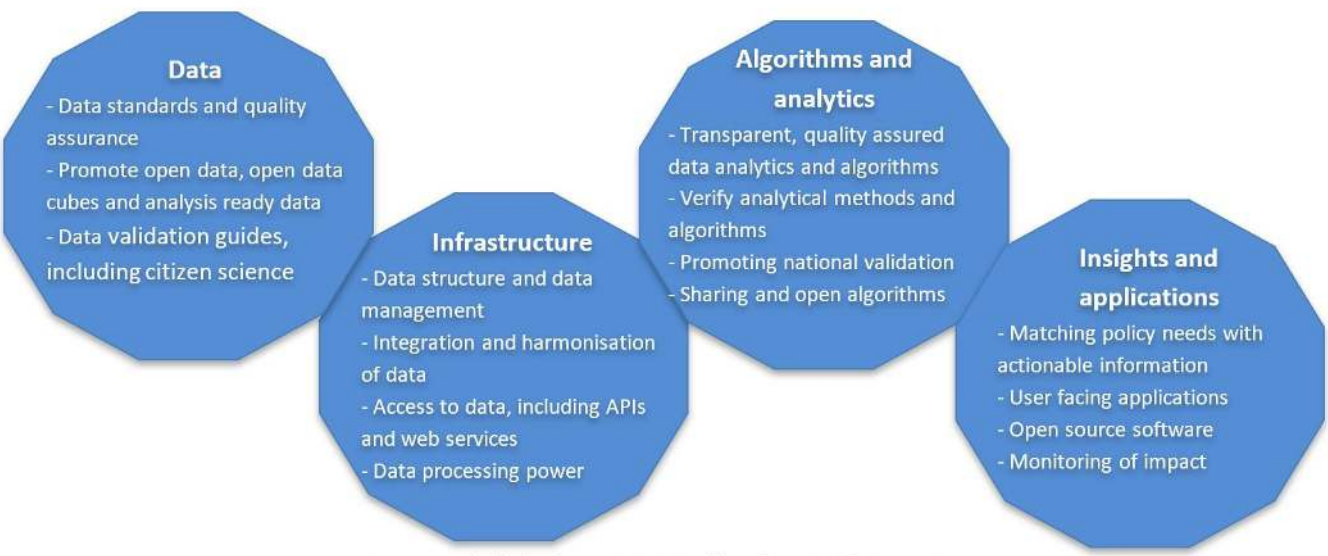
A global ecosystem for data, algorithms and insights must keep in mind that there will remain a need for national level data governance strategies and some data will remain only at the national level. Each country will adopt approaches relative to their political culture, values and social context. However, at the global level – the implementation of a global ecosystem must reflect agreed principles of international law and human rights. As governance processes and technology move at different speeds, one of the core governance approaches will rely on core ethical principles and social values. In this regard, the next generation of coders, computer engineers and data scientists may need an ethical protocol at the international level which countries and companies adopt and monitor. Such a protocol might follow a philosophy similar to the Hippocratic Oath that doctors take upon entering practice. In its original form, it requires a new physician to swear to uphold specific ethical standards and is used as a framework for self-enforcement. Perhaps a similar Turing protocol could be developed on basic ethical principles underpinning the application of frontier technologies backed by an AI tracking system to monitor compliance. This would also need to be coupled with training and developing a culture of ethics among coders and data scientists (as the ethical implications of decisions is not part of the core training for most engineers).

C) Components and vision

The ecosystem of data, algorithms and insights would aim to bring together big data on environment, official statistics, citizens science and other relevant data streams. The ecosystem would also include information related to data quality, data sources and collection methodologies. Ideally the ecosystem would provide a basis for understanding global trends and for drilling down to the national and community levels. Strategies for data management and analysis are needed for each of these scales.

Data collection would include satellites, drones, mobile phones, sensors, citizen science, official statistics, in situ data and other information. Due to the volume and

FIGURE 1: PROPOSED DIGITAL ENVIRONMENT ECOSYSTEM FOR DATA, ALGORITHMS AND INSIGHTS



4) Recognising the origin of data (Saboor 2013).

5) Acknowledging intellectual property rights of data

6) A digital object identifier (DOI) is a unique alphanumeric string assigned by a registration agency (the International DOI Foundation) to identify content and provide a persistent link to its location on the Internet. (APA Style 2019).

7) Decentralized Identifiers (DIDs) are a new type of identifier for verifiable, "self-sovereign" digital identity. DIDs are fully under the control of the DID subject, independent from any centralized registry, identity provider, or certificate authority. (Contributors to the Decentralized Identifiers 2019).

8) Token Binding has been included in the FIDO specifications as an important security measure. Token Binding cryptographically ties a token to a host, ensuring that the server knows that it is talking to the right browser. (FIDO Alliance 2018).

9) Metadata is information about the data collected (Knight 2017).

complexity of such data it would be impossible for all data to be centrally hosted. Thus, an ecosystem does not mean that data are pulled into a central location, but that information on accessing data is pulled together along with sharing algorithms and data processing power. This means bringing data, algorithms and processing power together in various clouds and/or connecting clouds together in a manner where data can flow among them. This would allow the integration of data from different sources and high data quality and frequency. For example, citizen science data could be used to validate ecosystem extent data which are based on satellite data, thus improving data quality or satellite data may be used to fill gaps between agricultural censuses which only occur every 10 years (Food and Agriculture Organization of the United Nations [FAO] 2019).

For each type of data, quality assurance guidelines would need to be developed over time. For example, citizen science can provide data for use or for validating other data through ground observations, creating knowledge and crowdsourcing. However, to build trust in this data, there must be agreed quality standards. On the other hand, for satellite data, data from in situ sensors and official statistics, international standards already exist.

Artificial intelligence algorithms will need to detect key patterns and relationships, extract insights, make predictions and help determine priorities for action. The adoption of AI for global environmental monitoring is already happening and should be embraced provided safeguards are put in place to address risks. AI and innovative applications of new technology can and should provide motivation for improved sustainable development and therefore instigate action.

4. DRIVING ACTION

Analytical products and insights can be used to promote the sustainable use of natural resources as well as nudge and incentivise both consumer behaviour and markets towards the sustainability and the achievement of the SDGs. To motivate progress towards the SDGs, analytical products must be easy to access, easy to digest and clearly linked to an environmental priority. Despite our best international efforts to build a global environmental governance system, the ecological integrity of our planet is at risk. Indeed, in 2018 more than 15,000 scientists in 184 countries signed a letter urging the world to address major environmental concerns. "*Soon it will be too late to shift course away from our failing trajectory, and time is running out*" (Ripple et al. 2017, p. 1028). Business as usual approaches to global environmental governance will not work. We need environmental solutions that work at the same speed and scale as the drivers of environmental degradation. A global data ecosystem is one of the prerequisites to achieving this wider goal.

The United Nations Framework Convention on Climate Change (UNFCCC) process has attempted to link necessary environmental action to climate change modelling in order to hold governments, companies and consumers accountable (United Nations Framework Convention on Climate Change [UNFCCC] 1992). The SDG targets provide a broader look at the environmental dimension of development which examine environmental drivers, pressures, impacts, state and responses. However, using the SDGs as a binding accountability framework is impaired by the lack of high-quality, real time global and local level data on many of the aspects of the SDGs. This impairment is exacerbated by very limited information on the interactions between environment, social and economic SDG targets. A recent report concluded that politicians have failed to grasp the severity of human impacts on the environment, which have reached a critical stage and threaten to destabilise society and the international economy. "*A new, highly complex and destabilised 'domain of risk' is emerging - which includes the risk of the collapse of key social and economic systems*" (Laybourn-Langton, Rankin and Baxter 2019, p. 5).

The international community needs to urgently close the gap between identifying global environmental problems and measuring the impact of proposed solutions and mitigation measures. It presently takes an average of four years to assess the level of compliance for each multilateral environmental agreement - a period of time that is equal to the turnover of governments and their political leaders. We need a real time and global picture of our progress towards achieving the SDGs.

5. FUTURE RESEARCH AND OPPORTUNITIES

In addition to using frontier technologies to map, measure and monitor our progress in advancing the SDGs, they are part of the solution to achieve the individual SDG targets. Frontier technologies will be essential in terms of influencing and nudging consumer behaviour, tracking the environmental footprint of product supply chains, improving efficiency in product design, assessing trade-offs and predicting impacts between alternative forms of land use and natural resource exploitation.

However, we must recognise that technological change and innovation occur at a speed and scale which is far beyond the capacity of many governments to both comprehend and regulate. The pace of change and the emergence of both positive and negative 'unknown unknowns' are by definition impossible to predict. The synergistic nature of technological change and innovation coupled with the potential for exponential adoption through network effects means they cannot be effectively governed with traditional approaches that rely on political consensus and top down regulatory frameworks. These can take years to forge at the national scale and decades at the global level in the multilateral system. In short, our political processes simply operate on a different timeline from technology. Furthermore, the governance challenges for each application of a particular blend of technologies are often extremely different. Many concerns are context specific and often are not addressed through broad and unfocused policy measures. Specific challenges relate to the flow of individual data sets between technologies and digital ecosystems, and to the privacy and security measures established individually and when used in combination. New agile governance models, creative commons licensing and an increased emphasis on ethics and values are required to guide technical development.

6. RECOMMENDATIONS

Member States are invited to consider the findings and recommendations of this discussion paper to improve national ecosystems of data, algorithms and insights and to request UN Environment to continue the SPB Forum Working Group on Data, Analytics and AI. The next focus of this working group should be developing an implementation strategy to ensure that a digital ecosystem of data, algorithms and insights is built for the environmental dimensions of sustainable development. Such a strategy would include:

1) Envisioning a digital ecosystem for the environment partnership by: considering the scope and structure of the ecosystem; identifying where data, algorithms and insights can be hosted depending on the type of information contained; mapping linkages with other relevant digital ecosystems; providing a framework for quality assurance and transparency; establishing a mechanism for protecting individual privacy; continuously identifying data, and data gaps; providing insight related to the most pressing and emerging environmental issues; matching the vision for the ecosystem together with a financing model; and avoiding data and technology monopolies in the environmental sector.

2) Collaboration and integration of other global best practices: many initiatives related to sharing data, including geospatial data, or to stimulate the development of analytical products already exist. UN Environment will work across the UN System and with other partners to leverage existing initiatives, for example the Environment Situation Room powered by MapX, the UN Global Platform on Big Data for Official Statistics, the UN Data Innovation Group, the UN Global Pulse projects on data science, Group on Earth Observation System of Systems (GEOSS), IOC-UNESCO's Global Ocean Observing System, etc. (United Nations [UN] 2015; United Nations Global Pulse [Global Pulse] 2018; United Nations Environment Programme [UNEP] 2019; United Nations Statistics Division [UNSD] 2019).

3) Using the science-policy-business interface to identify the demand for actionable, policy relevant insights, and public good applications: convene countries, companies, academics, civil society and international actors to match the data available with technological capabilities for generating insights in real time about the state of the environment at any scale. This will also help identify data gaps and democratise access to information for supporting government policies, academic research, financial investments, citizen action and sustainable consumption. In particular, public good applications required to monitor key environmental risks and opportunities should be identified even when these applications do not generate stand-alone private sector investments. These would include monitoring global environmental security risks, developing open source software, promoting consumer awareness and nudging towards sustainable consumption, and catalysing citizen science opportunities.

4) Developing a strategy for operationalising and financing an ecosystem for data, algorithms and insights: a strategy should be developed with key stakeholders related to data generation and collection, technological solutions and algorithms, insight analysis and business models. This strategy should be geared toward operationalising a global ecosystem through a step-by-step approach which identifies short term wins and long term modalities for the ecosystem.

5) Fostering engagement and rolling out the ecosystem: engagement with Governments, private sector partners, academics and citizens underpins the success of a global ecosystem. UN Environment could identify key partners that could stimulate national engagement, such as academia, UN Country teams and members of the Citizen Science Community, which would be both information users and contributors (Citizen Science Association [CSA] 2019). UN Environment would take into account the specific needs of developing countries and to ensure that digital technical solutions to environmental issues do not create additional inequality, but promote technology transfer and build capacity for uptake.

PART 2:

The Case for a

Digital Ecosystem

for the Environment

BACKGROUND

This white paper has been drafted by the working group of the UN Science-Policy-Business Forum on the Environment[10]. It is based on the outcomes of the first meeting of the Governing Consortium of the Science-Policy-Forum held in New York in May 2018 and the meeting of its Working Group on Data, Analytics and AI held in Paris in October 2018. It also draws from lessons presented during the Earth Innovation Forum held in Tallinn in September 2018 and the World Data Forum and the Eye on Earth Summit held in Dubai in October 2018. This paper aims to advance the ongoing dialogue with stakeholders to establish a vision and strategy to harness and deploy the power of the information age to solve global environmental challenges. In short, combining data with people and planet to achieve prosperity and peace. It is also a response to the request of the UN Secretary General for "bringing about a data revolution" (UN Secretary General's Independent Expert Advisory Group on a Data Revolution for Sustainable Development [IEAG] 2014). Building a conceptual vision for a global ecosystem of data, algorithms and insight can be used to achieve key environmental outcomes in support of the 2030 agenda, the Paris Agreement on Climate Change and the Sendai Framework for Disaster Risk Reduction (UN 2015; United Nations, General Assembly [UNGA] 2015; United Nations Office for Disaster Risk Reduction [UNISDR] 2015).

An ambitious vision and multi-stakeholder process are needed to ensure data can be used to generate insights as global public goods that can inform planning, decision-making, investing and impact monitoring in real time and over the long term. This vision should be built through a consultative process among private companies, member states, academia and civil society. In this regard, the UN Science-Policy-Business Forum on the Environment may offer an opportunity to anchor such a process. Established during the 3rd UN Environmental Assembly in December 2017, the forum leverages the expertise of its members support priority issues, initiatives and projects that are relevant to UN Environment's mandate and critical to the implementation of the SDGs.

During the first meeting of the UN Science-Policy-Business Forum on the Environment in New York in May 2018, a working group was established on Data, Analytics and Artificial Intelligence. This paper is a product of the working group. The working group also aims to address the issues related to establishing an open digital ecosystem of data, algorithms and insights and to demonstrate the utility of new data sources for environmental monitoring through specific examples and projects.

1. A DIGITAL ECOSYSTEM FOR THE ENVIRONMENT

A) Now is the time for action

Today, the ongoing digital revolution is generating more information than ever before on the state of the planet. A combination of satellites, drones, mobile phones, sensors, financial transaction technologies and devices connected to the IoT are collecting real time data that could transform the management of earth's natural resources and ecosystems. Spatialised information availability is expanding through: advancements in official statistical processes toward geolocating census and survey data; new techniques for better utilising administrative data (such as water provisioning, environmental permits, land ownership, etc.); the increased use of earth observation data and improved data dissemination processes. The combination of these innovations enables the mapping of: population, social development and economic actors in a way that makes it possible understand and predict the use of and demand for natural resources including the implications of environmental and climate change.

New data management technologies, artificial intelligence, block chain[11], cloud computing and cloud storage of information are making it possible to manage, share, process and analyse large volumes of data in near real time. A range of new technologies are also democratising access to environmental data, allowing academics, students and citizen scientists to be directly engaged in data collection, analysis and dissemination to the global community. The private sector uses data science and spatial information services to connect and influence people, places and products. They also offer the possibly to help green consumption by offering consumers more real-time data on the environmental footprints of different products and on the social and environmental performance of product supply chains (Handayani and Prayogo 2017).

In summary, governments, companies, academics, citizens and international organizations are all directly contributing to an explosion in the availability of global, national and local data. This is changing the way that the world thinks about and uses information. The newfound wealth of data is being generated at multiple scales across time and space allowing for monitoring of environmental change across communities, countries and continents. The level of access to spatialised information is unprecedented.

The opportunity to use this data to improve real time decision making on natural resources could also transform global environmental governance frameworks and multilateral environmental agreements. There is tremendous hope that decisions can be made, monitored and enforced using real time spatial and statistical data, thereby closing the gap between alarm, action and impact.

Indeed, it is the convergence of big data and frontier technologies, i.e. technologies that are emerging but have not yet been scaled for the mass market, that is unleashing the 4th industrial revolution. This new era is characterised by "a range of new technologies that are fusing the physical, digital and biological worlds, impacting all disciplines, economies and industries, and even challenging ideas about what it means to be human" (Schwab 2016).

The 4th industrial revolution provides an opportunity to transform the way environmental data is collected and managed; how major environmental trends, patterns, risks and opportunities are analysed; and how market transactions for environmental goods are conducted.

Technology and innovation can also support a critical enabling condition for better governance – the principle of transparency. Environmental transparency is a fundamental pre-condition and catalyst towards sustainability because it generates the data needed to achieve accountability, public participation and market pressure. A range of technologies including earth observation and sensors can both measure environmental performance and help make these data more publicly available. Generating this data is at the heart of how citizens can hold their public institutions and private companies more accountable – while also offering further opportunities for innovation.

A recent report by the UN Secretary General's Independent Expert Advisory Group on a Data Revolution for Sustainable Development highlights the importance of data, calling data "the lifeblood of decision making" (IEAG 2014, p. 2). Without high quality data that are collected in a spatial context, it is almost impossible to design, monitor, and evaluate effective policies that can achieve the Sustainable Development Goals (SDGs). The High-level Panel on Digital Cooperation was also convened by the UN Secretary-General to advance proposals to strengthen cooperation in the digital space among Governments, the private sector, civil society, international organisations, academia, the

10) This paper was co-authored by David Jensen (Head of Environmental Peacebuilding Programme and Co-director of the MapX platform for spatial environmental data) and Jillian Campbell (Chief Statistician) of UN Environment. Additional inputs from UN Environment were provided by Shereen Zorba, Alex Caldas, Pascal Peduzzi, Saiful Ridwan, Ben Simmons, Andrew Morton, Inga Petersen, Jason Jabbour, Barbara Hendrie and Shereen Zorba. It was mandated by the working group on Data, Analytics and AI of the UN Science-Policy-Business Forum, by the UN Environment Chief Scientist, Mr. Jian Liu and by the Director of the Division Policy and Planning, Mr. Gary Lewis. The paper reflects the inputs and feedback provided by the stakeholder consultation process listed in Annex I.

11) digital information stored in a public database (Fortney 2019).

technical community and other relevant stakeholders (UN 2018b). The Panel is expected to raise awareness about the transformative impact of digital technologies across society and the economy and contribute to the broader public debate on how to ensure a safe and inclusive digital future for all, taking into account relevant human rights norms.

As information is becoming the world's most valuable resource, there is an urgent need for governments, companies and citizens to consider how the digital ecosystem for data, algorithms and insights for the environment will be governed. Indeed, the time to act is now – before the governance of environmental data is concentrated in private hands without sufficient public access, transparency, accountability and quality control. Indeed, what would a Cambridge Analytica style scandal look like if similar measures had been used to target environmental policy, public campaigns and market investments? We are at an important crossroads where decisions that we take today will influence the scope and shape of how data and information can be fostered and shared for the coming decades. This paper sets out some of the key opportunities, risks and governance challenges related to creating data and insight which can be accessed by all governments and citizens as a global public good.

B) What's at stake?

A common vision is essential for building an *open digital ecosystem of data, algorithms and insights* that can generate trustworthy information in real time about the state of the environment and interactions between the economy, society and the environment. These insights need to be transformed into actionable evidence that can be easily understood by decision-makers, investors, consumers and citizens alike to maximise inclusion, transparency and accountability.

Progress toward the SDGs will not only require utilising new sources of data, but also an enhanced ability to bring together these data on the environment with relevant economic and social data. The ability to analyse real time information, as well as long term trends, is essential for ensuring a balance between the social, environmental and economic pillars of sustainable development. Policy options and trade-offs need to be modelled and future scenarios need to be visualised in a compelling manner.

Big data is a continuum that consists of a mix of commercial data requiring payment to access together with free and open public data that is maintained as part of a global public good. However, the portion of data that is private versus public warrants debate as do the incentives that are needed to push as much private data as possible into the public domain. Indeed, to move towards achieving the SDGs at the global, national and local level with environmental, social and economic considerations in mind, this envisioned data ecosystem must truly be open and inclusive. In this case, open means that all stakeholders would have access to aggregated information which is necessary for producing insights on the environment, while raw data and individual records may not be included in the ecosystem due to privacy and pricing concerns. This means that the ecosystem must represent data from diverse social and technological systems, including from academic, commercial, official government sources, traditional ecological knowledge and citizen science.

Investments are essential for closing the gap between the *potential* for new data to be used in the implementation of SDGs, and the *actual capacity* of countries and citizens to access and use data for effective decision making and monitoring. The most notable gaps are found between developed and developing countries, between private companies and public agencies, and between urban and rural settings.

The stakes are high as massive information asymmetries are already being exploited in a manner which amplifies existing inequalities and social grievances linked to management of natural resources. In short – information is power and those who control it could influence the future sustainability trajectory of our common planet.

Ultimately, we have twelve years remaining to fundamentally shift our global economic systems towards more sustainable trajectories in order to avoid wide scale environmental degradation, catastrophic climate change and loss of biodiversity. This kind of exponential transformation can only be achieved if it is catalysed and underpinned by leveraging the data, technology, innovation and connectedness offered by the 4th industrial revolution. Our traditional governance systems have been too slow to effectively respond to the environmental crisis that has been slowly unfolding for the past decades. A new approach is desperately needed whereby technology and innovation underpin and supercharge governance systems and consumer behaviour in a manner that accelerates and scales the necessary economic changes over the coming 12 years. This kind of massive transformation can be achieved, but it will require leveraging technologies that allow more rapid decision making based on accurate georeferenced data; the ability to seamlessly share data, insights and best practices among practitioners; and the capacity to engage private sector actors as well as citizens of planet earth in a common vision of action and mutual accountability.

C) Objectives

This white paper seeks to provide strategic considerations around *three main themes.*

1) Digital ecosystem for the environment: to consider the basic elements of a digital ecosystem for environmental data, algorithms and insights. These are divided into four areas: data; infrastructure; analysis & algorithms; and insights & applications.

2) Benefits, risks and governance aspects: to provide an initial mapping of the benefits, risks and governance challenges that need to be considered in establishing a digital ecosystem for the environment coupled with the incentive structures to integrate data from both private and public-sector actors.

3) Entry points and opportunities: to outline some of the underlying preconditions and opportunities for developing a culture of innovation, data use and analysis. This includes through: capacity building; laws, institutions, policies and norms; markets and finance; and digital economy business models.

3. COMPONENTS OF A DIGITAL ECOSYSTEM FOR THE ENVIRONMENT

A digital ecosystem is a distributed, adaptive, open socio-technical system with properties of self-organisation, scalability and sustainability inspired from natural ecosystems. A digital ecosystem managed by a commercial firm includes a global network of partners (suppliers, institutions, customers) and stakeholders through which business problems are solved. In many cases, digital ecosystem models include competition and collaboration among diverse entities.

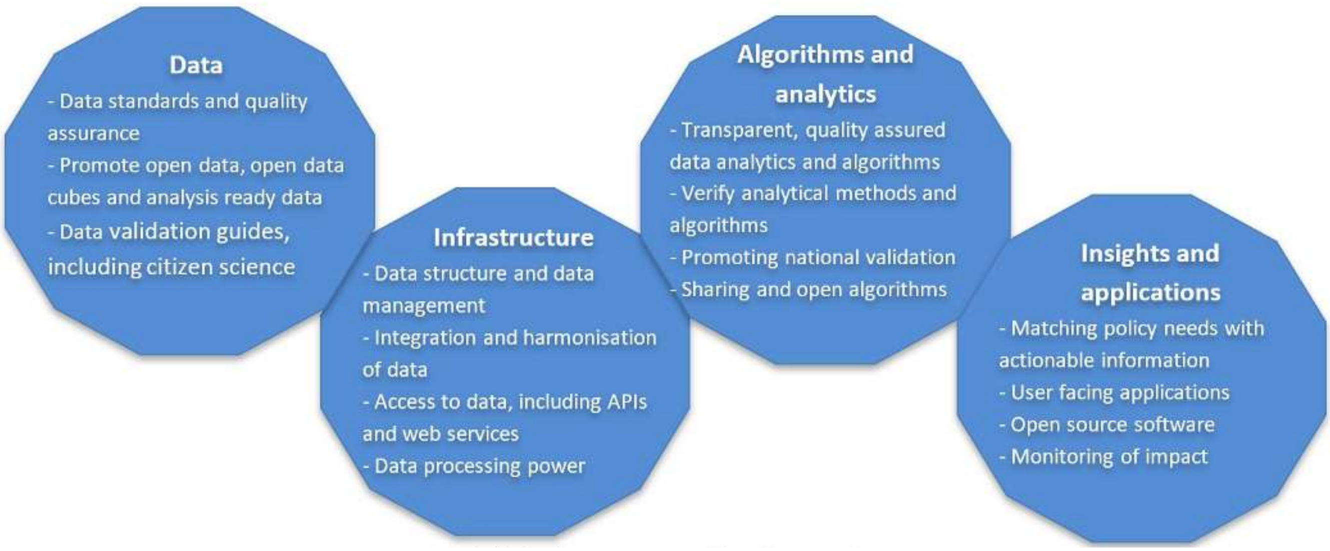
A digital ecosystem for the environment should include four main components: data; infrastructure; algorithms & analytics; and insights & applications. These are summarised in figure 1. A digital ecosystem basically transforms raw data using an underlying cloud infrastructure combined with algorithms and analytics into insights and applications that are accessed by users to help solve real world problems.

The digital ecosystem that is required to transform raw data can be understood as having an interlocking series of key building blocks that work together to produce a 'Flywheel Effect'. The basic idea is that once an organisation has all of the core technology pieces in place, the pieces have an energy of their own that drive other positive changes and innovations. The most critical aspect of a digital ecosystem is understanding how different technologies are combined and the fundamental dependences among them. Just like a real ecosystem, removing or changing individual components can have consequences and unexpected results.

Beyond the self-replicating aspect of the digital ecosystem, it is important to keep in mind that technology is only a means to an outcome - not the outcome itself. While commercial digital ecosystems are used to generate profits, global public good ecosystems can also be constructed to advance the SDGs and use technology to underpin their achievement. The following sections describe each of these components in more detail.

A digital ecosystem for the environment would not be hosted by a single institution or managed as a single database but would provide a framework for connecting data from different sources with algorithms and cloud computing services. The digital ecosystem would have data visualisation and dissemination of actionable insights. The infrastructure required for a digital ecosystem includes working with data providers to ensure that data can be included in the ecosystem, providing access to cloud

FIGURE 1: PROPOSED DIGITAL ENVIRONMENT ECOSYSTEM FOR DATA, ALGORITHMS AND INSIGHTS



computing services so that data can be analysed, and bringing together data and expertise with the demand for environmental insights and applications. Across all aspects of a digital ecosystem there is a need to promote sharing of experiences which can leapfrog knowledge and analysis across domains and locations.

A) Data

Data can arise from many different sources. Data stems from academic research; from administrative data maintained by Government ministries (for example, education registers or environmental permits); from surveys and censuses carried out by Governments and from a variety of technologies, including, satellites, sensors, drones, mobile phones, financial transactions and other digital devices.[12]

TABLE 2: NONEXHAUSTIVE LIST OF KEY DATA SOURCES

Data source	Statistics
Satellites	1,738 Satellites in orbit in 2017 5,700 generated scenes per day (open source) Landsat archive 32 years – over 5 million scenes (Union of Concerned Scientists [UCS] 2018).
Internet of Things (IoT)	IoT creates 400 zettabytes of data per year (1 zettabyte is 1,000,000,000,000 Gigabytes Or 2 billion years of uninterrupted music on spotify) (Worth 2014).
Sensors	15.4 billion sensors in 2015 75 billion by 2025 (Columbus 2016).
Mobile phones	5 billion unique mobile phones offering opportunities for geocoded data collection as well as daily movements (Sawyers 2017).
Mobile apps	3 million unique apps (Statista 2018).
Internet access	Over 4 billion people, 54% of population (Internet World Stats 2018).
Censuses and surveys	More than 7 billion people are covered by censuses every 10 years (Scott 2005, p. 14; Baffour, King and Valente 2013, p. 11). A variety of surveys are conducted by all Governments around the world at varied periodicity.
Citizen science	eBird (500 million records), Artportalen (Sweden: 58 million) Artsdatabanken (Norway: 16 million), and iNaturalist (16 million),(Moen 2017, Swedish LifeWatch 2017; eBird Team 2018; iNaturalist 2019b).
Publications and documents	A wealth of data is available in academic publications including over 2.2 million scientific articles in science and engineering alone in 2016, corporate reports encompassing over 50,000 corporate sustainability reports found in one database alone and other documents which can be made discoverable using web scrapping algorithms (Global Reporting Initiative [GRI] 2016; National Science Board [NSB] 2018, p. 112).
Administrative data	Governments, utility companies, and other services providers maintain data related to registration, transaction and record keeping. Many countries currently have records-keeping requirements in place and those without such regulations are under pressure to form new requirements and practice thorough records-keeping, resulting in a wealth of data spanning government bodies (World Bank 2000).
Finance data	Virtually all non-cash financial transactions are recorded. Financial databases cover 189 countries to date, this includes every region and income level in the world (International Monetary Fund [IMF] 2017; World Bank 2019).

12) This combination of data is often referred to as "big data" meaning data sets that are so large and complex that traditional data-processing software are inadequate to deal with them.

Different types of data span geographic scales and time periods from local to global level. Data can either be structured in a traditional database or unstructured. Data include a high diversity of data quality which can be generated by multiple actors including international organisations, governments, companies, academics and citizens. Data curation is a way to ensure high data quality using data authentication and management. Ultimately, data curation does not only ensure high quality of data, but it also makes data use more efficient by improving data discovery and analysis for users and integrating data (Knight 2017). Some of the statistics in Table 1 showcase the volume data currently being generated. Key data sources that are relevant to tackle environmental issues and the management of natural resources are included in Table 2 (non-exhaustive list).

The above represents a picture of the current data available; however, the volume of data generated is rapidly expanding by the day. For example, the number of satellites that Governments and private sector organisations have put into space has expanded from a single satellite in 1957 to more than 1,700 active satellites today; and the capabilities of satellites to capture and transmit data provide new opportunities for understanding the planet (USC 2018). For example, a company called Planet is able to map the earth every day at 3m resolution while the Sentinel series of satellite missions will support mapping of the planet every 7 days at 10m resolution coupled with radar and high spectral frequencies for monitoring oceanographic change, air quality, atmospheric conditions and other environmental variables (European Space Agency [ESA] 2018).

The potential to use this range of data for global environmental monitoring and governance is unprecedented. However, access to data alone is insufficient. A robust digital ecosystem is needed to transform that data into information, insights, indicators, investment decisions and impacts. Data from different sources need to be able to be integrated and processed.

Data provenance is a critical investment to support the quality and accountability of the data commons. This includes data attribution, licensing, digital object identifiers (DOI), Decentralised identifiers (DIDs), token binding, meta data using ISO standards, etc. Increasingly metrics will be needed to measure data integrity.

B) Infrastructure

As data points can be accessed in the location where they are currently stored, the design of a digital ecosystem would provide a network of data sources that can be linked to cloud computing services. This would allow users to access massive processing power for data analysis; to integrate data from different sources and to use data for global, national or local level analysis. The storage of open algorithms and descriptions of algorithms would allow users to learn from the experiences of others. Insights generated could be shared publicly and once validated, feed into visualisation platforms such as the World Environment Situation Room of UN Environment which uses MapX for geospatial data and a relational database structure for indicator data (UNEP 2019).

A cloud-based infrastructure for the digital ecosystem has many benefits, but it does rely on users having regular access to the internet in order to share data, create algorithms or visualise insights generated. Currently, there is a need to improve information and communication technology (ICT) infrastructure in order to maximise the value of a digital ecosystem, but as global connectivity is increasing this will be less of a constraint. In particular, the global roll-out of 5G technology for mobile communications over the next few years will provide more affordable, reliable, faster access for sharing data and accessing information which will help lessen the information divide (Herman 2018).

As data management techniques and data infrastructure differ across stakeholders, the core of a digital ecosystem for the environment is the need to ensure effective data management. This includes ensuring: that environmental data is accessible and transparent, that information on data standards is kept so data can be integrated with other data sources and the data custodians are committed to storing and maintaining data over time. In this regard, a digital ecosystem for the environment should also promote open data access and openness and standardisation of application programming interfaces (APIs)[13], including data derived from citizen science. This includes promoting existing data sharing standards, including the Statistical Data and Metadata eXchange (SDMX)[14] which is endorsed by the UN for sharing data between national and international partners; the Open Geospatial Consortium (OGC)[15] which is adopting web map services (WMS)[16], open

13) a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.
14) SDMX, which stands for ***Statistical Data and Metadata eXchange*** is an international initiative that aims at standardising and modernising (“industrialising”) the mechanisms and processes for the exchange of statistical data and metadata among international organisations and their member countries. (Statistical Data and Metadata eXchange [SDMX] 2018).
15) The Open Geospatial Consortium (OGC) is an international industry consortium of over **526** companies, government agencies and universities participating in a consensus process to develop publicly available interface standards. (Open Geospatial Data Consortium [OGC] 2019a).
16) The OGC WMS (Web Map Server) standard specifies the interface and parameters to dynamically request maps from a server. Every OGC WMS is individually configured and can serve a multitude of different maps, combination of layers and can optionally even be styled with different cartography(OGC 2019b).

data cube efforts[17], web feature services (WFS)[18], web coverage service (WCS)[19] and web processing services (WPS)[20]; and the GEO DAB which is brokering a framework that interconnects hundreds of heterogeneous and autonomous supply systems (the enterprise systems constituting the GEO metasystem) by providing mediation, harmonisation, transformation, and Quality of Service (QoS) capabilities. These existing data sharing standards create a starting point for the digital ecosystem to foster open data access and effective data management.

There are many of sectoral examples of success in building open data infrastructure that could be drawn from. For example, the international network and research infrastructure convened through GBIF—the Global Biodiversity Information Facility—provides free and open access to more than 1 billion individual records on where and when species have been observed or collected. This georeferenced, open data uses an agreed set of Biodiversity Information Standards.

a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.

SDMX, which stands for Statistical Data and Metadata eXchange is an international initiative that aims at standardising and modernising ("industrialising") the mechanisms and processes for the exchange of statistical data and metadata among international organisations and their member countries. (Statistical Data and Metadata eXchange [SDMX] 2018).

The Open Geospatial Consortium (OGC) is an international industry consortium of over 526 companies, government agencies and universities participating in a consensus process to develop publicly available interface standards. (Open Geospatial Data Consortium [OGC] 2019a).

The OGC WMS (Web Map Server) standard specifies the interface and parameters to dynamically request maps from a server. Every OGC WMS is individually configured and can serve a multitude of different maps, combination of layers and can optionally even be styled with different cartography (OGC 2019b).

The Open Data Cube (ODC) is an Open Source Geospatial Data Management and Analysis Software project that helps you harness the power of Satellite data (Open Data Cube [ODC] 2019).

The Web Feature Service (WFS) represents a change in the way geographic information is created, modified and exchanged on the Internet. Rather than sharing geographic information at the file level using File Transfer Protocol (FTP), for example, the WFS offers direct fine-grained access to geographic information at the feature and feature property level (OGC 2019c).

A Web Coverage Service (WCS) offers multi-dimensional coverage data for access over the Internet (OGC 2019d).

The OpenGIS® Web Processing Service (WPS) Interface Standard provides rules for standardizing how inputs and outputs (requests and responses) for geospatial processing services (OGC 2019e).

C) Algorithms and analytics

While data are the foundation of the digital ecosystem, it requires both processing infrastructure together with algorithms and analytics to extract relevant insights and business intelligence. Indeed, big data must be coupled with analytical methods involving artificial intelligence and machine learning to be used to detect patterns, identify trends, determine interactions, optimise variables and make predictions.

The question of who pays to build and maintain this data processing and analytical infrastructure is critical. For example, Google Earth Engine uses cloud computing to bring the algorithms to the data as opposed to bringing the data to the processing unit. This has tremendous potential to be harnessed to better monitor the planet. At the same time, it is also critical to ensure access to global data is well managed, that the use of global data as a global public good is fairly financed and that governments have a voice in the governance and scope of the use of global data. The business model for this kind of public good platform offered by a private sector actor should be transparent so that governments can choose to use it with full knowledge of the risks, requirements and trade-offs.

The final applications and websites which consume data feeds and curate the data into specific user products are incredibly dynamic. These applications receive, remix and reshape multiple data streams in a manner where the data can "flow". Indeed, one of the goals is to give users the power to freely innovate, analyse and recombine data in

17) The Open Data Cube (ODC) is an Open Source Geospatial Data Management and Analysis Software project that helps you harness the power of Satellite data (Open Data Cube [ODC] 2019).
18) The Web Feature Service (WFS) represents a change in the way geographic information is created, modified and exchanged on the Internet. Rather than sharing geographic information at the file level using File Transfer Protocol (FTP), for example, the WFS offers direct fine-grained access to geographic information at the feature and feature property level (OGC 2019c).
19) A Web Coverage Service (WCS) offers multi-dimensional coverage data for access over the Internet (OGC 2019d).
20) The OpenGIS® Web Processing Service (WPS) Interface Standard provides rules for standardizing how inputs and outputs (requests and responses) for geospatial processing services (OGC 2019e).

ways that cannot be predicted. For example, existing citizen science initiatives on air quality have increased the awareness of air quality issues and have helped fill in data gaps by providing a mechanism for citizens to provide data which complement existing data models.

D) Insights and applications

Data products are only useful if they provide actionable information which can inform policy; improve transparency and accountability; influence investments, business practices and markets; change consumer behaviour or sway public opinion. Currently, many existing data products, statistics and indicators are under-utilised or not fit-for-purpose. Developments in new data sources, data science and analytical techniques provide an opportunity to create useful information. To guarantee the information is well-adapted, the audience (i.e. data users) must be engaged throughout the process to ensure that the products developed will provide the information in a way that is easy to access and easy to digest.

One new data technique to provide actionable information includes the Global Climate Change Initiative Land Cover Database of the European Space Agency which can be used to identify trends and hotspots for land degradation and is used by the IPCC. Within the Fintech[21] world, the "Ant Forest" app gamifies actions to reduce carbon emissions among the 700 million users of the AliPay[22] ecosystem in China. When enough points have been earned to grow a virtual tree, it is converted into a real tree, planted in the desert in Inner Mongolia.

4. POTENTIAL BENEFITS, RISKS AND GOVERNANCE CHALLENGES

An emerging ecosystem of data, algorithms and insights could potentially transform the way that environmental data is collected and managed; how major environmental trends, patterns, risks and opportunities are analysed; and how market transactions for environmental goods are conducted. As with any technology, there are trade-offs to make in terms of addressing potential benefits, risks and governance challenges. The following section outlines some of the most important considerations.

A) What are the potential benefits?

The first question relates to the potential benefits that could flow to environmental stakeholders from increased access to a digital information ecosystem. What are the main benefits and opportunities offered by the 4th industrial revolution for the environment? Potential benefits may include:

1) More efficient and lower cost data processing technologies: the processing of large global data sets can now happen at a fraction of the cost and time compared to a decade ago. For example, the Global Surface Water Explorer which uses a timelapse sequence of the Earth using Landsat satellite images takes around 2 million hours of computation time (European Commission's Joint Research Centre [JRC] 2016). This would have taken a single computer around 228 years to process - but today takes a parallel series of 66,000 computers in the cloud only 1.5 days to crunch. Today we have the ability to process data on a global scale to monitor the vital signs of the planet (JRC 2016).

2) Automated monitoring with near real time spatial data: one of the largest potential benefits involves the ability to set up automated artificial intelligence algorithms that are applied to a combination of data feeds to monitor specific environmental issues and to automatically detect certain land use changes or movements. For example, both Global Forest Watch and Global Fishing Watch offer regular global monitoring of deforestation and tracking of the global commercial fishing fleet respectively (Global Fishing Watch 2019; Global Forest Watch [GFW] 2019). Importantly, frontier technologies are generating huge amounts of spatial data that can be triangulated to monitor a range of different environmental trends across multiple scales. This offers the potential for earlier identification of risks and focused action.

3) Improved transparency, data quality and data integration: ensuring that methodologies, metadata and information about data integrity are publicly available and discoverable will provide assurance to users that they are using the best available data. Additionally, this will inform which data can be pulled together to create integrated analysis across multiple datasets from multiple sources. For example, a highly useful analysis of potential risks to water security could arise from integrating: environmental data on ecosystem cover, water quality data, geospatial population data and data on the location of industry.

4) Accelerating transformation of science into policymaking and impact monitoring: data and analytics can provide an improved evidence-base for policy makers, in particular through modelling different policy options and developing forwarding looking scenarios. As the sources of

21) Financial technology, often shortened to FinTech or fintech, is the new technology and innovation that aims to compete with traditional financial methods in the delivery of financial services. The use of smartphones for mobile banking, investing services and cryptocurrency are examples of technologies aiming to make financial services more accessible to the general public.
22) A digital payment platform (Alipay 2019).

data grow richer and more diverse, there are many ways to use the resulting insights to make decisions faster, more accurate, more consistent, and more transparent (Henke et al. 2016). For example, smart cities with full IoT capabilities can monitor air quality or hyper-local weather conditions.

5) Increasing citizen engagement and co-creation of knowledge: it is becoming apparent that professional science alone cannot provide information at the scales and resolutions necessary to understand environmental change. The new ecosystem offers tremendous opportunity for citizen science, local engagement and public participation in decision-making and compliance monitoring. Importantly, there can be a multidirectional exchange of data between scientists, citizens, governments and companies. The Blue Sky map app is a good example whereby real-time air quality data for 380 cities in China and pollution data from 9,000 companies can be accessed and then shared on social media to name and shame companies (Qin 2015). Across the biodiversity community mobile applications for citizen science and real-time environmental sensors are being increasingly used, as an example, the iNaturalist app is a crowd-sourced species identification system and occurrence recording tool, driven by citizen science with over 16 million records (iNaturalist 2019b).

6) Socioeconomic and educational opportunities: this proposal offers opportunities for the wealth of existing technically-competent workforce. Promoting an ecosystem as for the global public good means that the careers and opportunities created in this ecosystem would allow benefit individuals interested in technological solutions to sustainable development in the public sector. On top of offering opportunity to the existing technical community, there are new opportunities to learning young professionals in the science, technology, engineering, and math (STEM) fields. A learn-by-doing opportunity for young professionals is vital to gaining necessary skills to push new innovation using the unparalleled resource of such an ecosystem.

7) Engagement of the business community: companies are becoming increasingly engaged in the evaluation of the sustainability and environmental soundness of their business processes, including through a dedicated SDG indicator on Corporate Sustainability Reporting (SDG indicator 12.6.1). Additionally, there is a growing recognition of the value of Corporate Sustainability Reporting for not only large multi-national companies but also small and medium size enterprises. The data and information contained in such reports can provide a wealth of information relevant for targeting policy interventions while helping to create incentives and awareness towards greener consumption.

8) Enhancing investor and consumer awareness and transparency: real time data on the environmental performance and the supply chains of different commodities and raw materials has the potential to dramatically influence investor and consumer awareness and behaviour. There is huge potential to use data and artificial intelligence algorithms to help nudge consumers to make more informed product choices while also naming and shaming companies with poor environmental performance across their supply chains. For example, the Earth Accounting app enables consumers to access product information around specific issues of interest (Evans 2016). Google and Facebook could also use a combination of big data and AI to help consumers compare and select more sustainable products or offer "opt in" filters for advertising to target and promote more environmentally friendly products. Thomson-Reuters are using big data to inform their Environmental, Social and Governance (ESG) Index[23] to help mitigate and assess the risk of companies to inform sustainable investment decisions.

9) Decentralised and trusted environmental transactions: the environmental crisis is growing partly because of a lack of trust and direct connection. The increasing distance between multiple actors who are unknown to each other exemplifies this lack of connection that exists between companies, governments, and individual consumers. This distance creates many opportunities for fraud, failed policies and a lack of direct responsibility. The time may be ripe for 'crypto governance', in which trust, rule of law and enforcement are supported by frontier technologies such as blockchain and smart contracts (Chapron 2017). For sustainability, blockchain technology could be a game-changer by enabling decentralised transactions and contracting linked to natural resources. Smart contracts with environmental performance conditions can be connected directly into IoT sensors and environmental oracles (trusted databases) to verify compliance against certain performance criteria. Datasets could also be managed using blockchain technology in order to track usage and establish mechanisms for micropayments.

B) What are the potential risks?

Moving beyond these potential opportunities, there is also a need to consider a series of questions linked to potential risks. If information is power, then those who control access to information and processing capacity hold more power than other stakeholders. We need to carefully

23) Tracks the performance of companies with superior ratings for environmental, social and governance practices (Thomson Reuters 2018).

understand the implications of potential power imbalances and how these can be mitigated.

One of the most important considerations going forward is that the infrastructure needed to process data and the algorithms needed to extract insights are currently held by a handful of technology companies. While public institutions are increasingly deploying these technologies, their capacities and access to financial resources often lags behind private sector actors. Public sector actors simply cannot keep up with the pace of innovation together with the engineering capacity and research and development funding that private sector companies can deploy. As a result, public-private partnerships will likely be needed at various points across the ecosystem to tackle global environmental problems and contribute to positive public outcomes. New frontier technologies with public good environmental applications may also need help to accelerate and scale through blended public and private financing. Against this background, potential risks to consider include:

1) Platform monopolies and predatory pricing: by having a near monopoly on the ability to process big environmental data, tech firms will face a temptation. While their initial intentions to build data platforms might be noble, once these platforms begin to scale, there may well be a shift to a winner take all mentality. “Free” is often transformed into “pay to play” once the revenue potential becomes clear. If fundamental dependences are created between companies and public sector partners, what safeguards are needed to reduce the potential for progressive price hikes and prevent predatory pricing?

2) Privacy violations: much of the data collected from individual transactions is maintained in the private sector. Many countries do not have strong legal frameworks to regulate the sharing and anonymisation of such data where it may have important environmental applications. There is a need to strike a balance between ensuring the privacy of individuals while utilising the full potential of the data available. What are the implications of data breaches and privacy violations for environmental data, including the location of strategic natural resources and the environmental performance of individual firms?

3) Lack of understanding of data quality: more and more data are being generated by different sources. This includes data which employ high-quality data standards and data which are created without a standard or created with a particular bias. This creates a challenge for governments, communities and individuals in determining which data can be trusted. There is also a need to distinguish between official government sources of data and non-official sources that may be the best available.

4) Information asymmetries and inequities: data are owned and generated in particular nodes of data intensity, which creates a potential for massive information asymmetries among companies, governments and local communities. If only the largest commercial firms can afford to pay for AI-powered global monitoring of data, what negotiating advantage does this bring for exploration and contracting of high value natural resources? How can governments and local communities possibly negotiate a fair deal when they lack access to such high-quality analysis and insights? This kind of monopoly of knowledge could create a massive imbalance of power in transactions linked to natural resources – a worst case market failure and catastrophe for sustainable development if it leads to lopsided and investment deals and unfair benefit sharing outcomes. Such an asymmetry of data may additionally lead to speculative investment from the entities with the greatest access to information, which could lead to disrupting global markets, stocks and currencies as well as lead to major speculative investments in land, water and other commodities allowing for local shortages and price spikes.

5) Conflict of interest between profit making, public goods and green-washing: to avoid regulation and public scrutiny, many technology companies have jumped on the “big data for social good” bandwagon and often frame their mission as making the world a better place. It is important to understand how such firms can resolve potential conflicts of interest that might arise between their public mission of doing good together with the private mission of making money. In many cases, the global public good of protecting a certain natural resource could be in direct contradiction with a commercial interest to sell the same data to exploit it. How will this conflict be managed? While many companies have adopted ethics policies that requires disclosure of potential conflicts of interest – it is uncertain if these policies will truly manage conflict.

6) Environmental impact of technology: CO2 footprint of this technology would contribute to the issues that the proposal is tasked with solving. In 2012, about 5% of the world’s electrical energy was consumed by ICT and this released almost 2% of total CO2 emissions. These numbers are increasing, but the increases in energy use and emissions are expected to be balanced out by decreases in other fields (Gelenbe and Caseau 2015). This risk calls for energy use and emissions tracking to confirm that the net impact is positive.

7) Blended financing[24] and public subsidies: if public funds and subsidies are made available to commercial firms to scale frontier technologies though blended financing, how can the underlying intellectual property, data and algorithms be open sourced and released into the public domain? How can blended financing be used as an incentive to on-board companies in the use of new technologies to cover the public good cost of engagement rather than simply subsidise the underlying business model? Additionally, how can private sector funds and in-kind technology be leveraged to support global data products which have no immediate commercial value and are only useful for public good?

C) What are the governance challenges?

Finally, given the above combination of potential opportunities and risks, it is essential to ask how the entire digital ecosystem can be governed in a manner where governments and citizens have a voice in decision-making and where the lines of accountability are clear. Going forward, the main question for public officials is to agree on the scope and shape of the governance framework for environmental data. In particular, how to ensure that it becomes a key component of the global environmental governance framework and maintained as a global public good? In this regard, a number of key governance questions need to be addressed:

1) Standards and transparency: a series of international standards will be essential to underpin the convergence of frontier technologies. Interoperability standards are necessary ensure data can be seamlessly shared or streamed on different platforms and integrated for analysis. Similar standards regarding metadata, data taxonomies and classification, and data integrity should follow. Full transparency is needed on who generated the data, how it was analysed, how quality was controlled and who takes final responsibility for the content. The SDG indicator framework provides a starting point for ensuring the use of standards for a set of 241 indicators but does not apply more broadly to other data and indicators. Therefore, while standards for the digital ecosystem can use the existing SDG standards as a model, new standards need to be developed to address critical questions.

2) Data sharing laws and incentives: as companies begin to deploy sensors and IoT applications across their supply chains and operations, they will start to collect huge qualities of useful environmental data that could populate the data in the digital ecosystem. How much of this data should companies be required to share as part of their legal or social licence? How can the privacy of individuals be ensured within the legal framework? What incentives are needed to share non-commercial data to maximise the amount of data in the public domain? How will governments and other public-sector actors who are deploying sensors in IoT applications such as smart cities manage and publish this data?

3) Open and accessible data and algorithms: open data are data that can be freely used, re-used and redistributed by anyone and are essential for improving data governance. Currently, APIs are the best way of sharing data which can be re-used and redistributed. We are now faced with the challenge of data spread across multiple formats such as excel tables, pdf documents and unconnected databases which are difficult for users to access. A global ecosystem should consist of a mix of open and public data, combined with private data with use restrictions in place to ensure privacy and confidentiality is maintained. This ecosystem should include a basic set of georeferenced and open data with international standards and an existing international framework (such as the SDGs or multilateral environment agreements). This data should be coupled with relevant environmental data for assessing the state of the environment and other social and economic data which are needed for analysing the interactions between society, the economy and the environment. These open data standards apply to data generated at any level (national, sub-national, regional or global). As artificial intelligence algorithms needed to process open data begin to proliferate, it will be equally important to publish them in an open format to avoid potential "black box" applications.

4) Quality control/quality assurance: as private sector actors occupy an increasing role in the delivery of public environmental monitoring services using data and their related algorithms, a minimum level of quality control/ quality assurance is needed to build public trust. All methodologies and metadata should be publicly available in order for data users to ensure that the data are not only of high quality and unbiased but also are fit for purpose. Importantly, guidance is needed on the data layers that can be mixed in a scientifically sound manner that takes into account spatial and temporal resolution, spatial autocorrelation and the modifiable areal unit problem (MAUP).[25] New verification and certification standards will be needed to indicate the quality of the underlying analytical process.

5) Privacy and data security safeguards: guidance will be needed on the set of organisational policies, procedures and maintenance of security measures that are designed to protect private information, data and access within the

24) Blended finance is the strategic use of development finance for the mobilisation of additional commercial finance towards the SDGs (Organisation for Economic Co-operation and Development [OECD] 2016).

25)a source of statistical bias that occurs in the aggregation of spatial data that can significantly influence the results of hypothesis tests ecosystem. Strong legal frameworks are essential for protecting the privacy of individuals, particularly due the fact that much data are privately owned and the intrinsic value of these data.

6) Intellectual property and revenue sharing: new intellectual property laws need to be developed to account for derived data products based on a mix of underlying data sources, including commercial and non-commercial data. In other words, how can intellectual property protections apply to a final composite data product with various input data layers subsisting of different commercial use restrictions. Ideally, data sets should be given a unique digital fingerprint so that users can have absolute assurance on the history of the data set, the most recent version, the ownership and the end user license agreement (EULA). This would also allow the custodians of data sets to track how their data are being used in data applications and participate in and micro-payment systems.

5. ENTRY POINTS AND OPPORTUNITIES FOR ENGAGEMENT

Clearly, planet earth desperately needs the best data and processing power humanity has to offer. As international organisations and countries move forward in partnership with the private sector, a vision is needed on how different components of an ecosystem for environment data, algorithms and insights needs to be built, governed and financed. This section provides a list of entry points and opportunities.

A) Capacity

Currently capacity gaps in collecting data, employing frontier technologies and creating insights exist between different countries, sectors within countries, and especially between the public and private sector. Building a digital ecosystem for the environment which provides global and local insight, including for vulnerable and isolated communities, will require improving human, financial and infrastructure capacity at all levels. This would include:

1) Training and capacity building: it is essential that the needs of data users are placed at the centre of all efforts. Training and capacity building programmes will be needed to reduce the potential for massive information asymmetries between different stakeholders.

2) Leveraging private sector capacities and infrastructure: consider how to structure public private partnerships that will be required to process data and apply AI algorithms using the infrastructure and capacities of major technology firms.

3) Trust building and buy-in: many Governments and other data users lack the capacity to analyse the utility of new data technology and artificial intelligence applications. As a result, the uptake of globally derived data products is low. There is a need to form partnerships which allow users to increase their engagement and trust while at the same time being able to leverage new data and AI algorithms which are being generated by others, including the private sector.

4) Citizen awareness and engagement: creating information that can be provided to the public in a digestible way increases the ability of citizens to better engage in policy processes and insist on accountability measures. Citizen science communities also provide an opportunity to better engage with the public.

5) Informing consumer awareness and choice through new techniques to stimulate engagement with data and insights: there is a tremendous opportunity to use data about the environmental footprint of products and their supply chains to inform consumer choices using mobile apps and e-commerce suites. Using blockchain technology for supply chain management would permit companies to offer consumers assured information on the Environment, Social and Governance (ESG) performance of products. The consumer would have absolutely certainty on the supply chain and authenticity of the product by accessing the blockchain history.

B) Institutions, laws, policies and norms

Finding a balance between protecting privacy and security, recognising the economic value of data and promoting open data requires strong legal frameworks and institutional mechanisms. Currently, advancements in data generation have outpaced the development of legislation and policies related to data generation. A digital ecosystem for the environment, and more broadly the entire global composite of data and analytics should fall under a governance system which includes institutions, laws, policies and norms which may include the following elements:

1) Innovation culture: help identify and create institutional incentives for sharing data, developing innovative applications and building internal capacity for uptake.

2) Institutions, laws and policies: provide technical guidance on legal frameworks related to data governance, openness, accessibility, privacy, and cost sharing.

3) Disclosure and due diligence: promote the disclosure of companies on the use of data sets and AI algorithms for investment decisions, environmental impact assessments and due diligence. A global mechanism is needed to report and redress the negative unintended consequences of data and artificial intelligence. This mechanism should be a resource for when countries feel that data is being used in a non-competitive and monopolistic manner, or if sensitive data is being collected without consent.

4) Environmental requirements in smart contracts: looking even further into the future, there is huge potential for blockchain technology and "smart contracts" to revolutionise the management of natural resources and the environment. Indeed, the moment that investment contracts, green bonds or resource concessions move into smart contracting there will be a massive opportunity to include social and environmental performance requirements directly in the blockchain. Smart contracts would automatically execute once a set of agreed conditions are met, such as emission standards, water quality or energy production. They would run exactly as programmed without any possibility of censorship, fraud or third-party interference. A smart contract could be informed by traditional monitoring data from a public-sector actor or automated to rely on data from an environmental sensor, a satellite image and an artificial intelligence algorithm.

5) Information sharing and public verification of smart contracts: one of the most interesting dimensions of the smart contract is the potential to support information sharing among all stakeholders. Everyone involved in the contract can be informed in real time of each execution or addition to the blockchain thereby maximising transparency and trust. Smart contracts could even offer the possibility for a benefit verification mechanism among stakeholders. Each stakeholder could digitally report on the achievement of the contractual requirement in each block, and once all conditions are met, the contract block would execute forward. This could enhance participatory environment monitoring and give local communities a direct voice in the verification of agreed jobs, revenues and other benefits.

6) Ethical frameworks: as technological innovation moves faster than institutions, it must be steered with strong ethnical and value frameworks. Each country will adopt approaches relative to their political culture, values and social context. However, at the global level – the implementation of a global ecosystem must reflect agreed principles of international law and human rights. A new social contract between companies, governments and citizens is also required where mutual obligations and responsibilities are spelled out. The cost of doing business anywhere in the world should be the release of relevant non-commercial data into the digital ecosystem for the environment s that can be used to measure SDG progress. While protection of commercially sensitive and strategic data is important – it is now possible to extract a subset of this information or aggregated information that can be open and accessible.

C) Markets and finance

To create a global culture that encourages the use of data and insights for action will require market and financial incentives. These incentives may be dictated by policy, by creating specific taxes or subsidies, by allocating money for research and development, or by providing a means to improve or change public perception

1) Financing for innovation research and development: must be identified to speed the uptake of relevant frontier technologies for the environment through public and private financing (grants, guarantees or loans). The objective is to stimulate and leverage private sector capital for global public goods and to use data to measure the positive environmental impacts at scale.

2) Environmental performance monitoring policy requirements: establish standards for environmental impact assessment and environmental performance monitoring, which include disclosure of relevant non-commercial data into the digital ecosystem. This should include both baseline data as well as regular environmental performance monitoring.

3) Corporate sustainability reporting: promote global sustainability reporting of companies with differing level of ambition depending on the company size. There should be a mechanism for small and medium companies to demonstrate the efforts that they are making to achieve sustainability. For larger companies and multinational companies, a more stringent set of information will continue to be required through legal obligations.

4) Blended finance and green bonds: for projects which disclose relevant non-commercial environmental performance data, blended finance and green bonds could automatically stream into the global data trust with the option for anonymisation. Green bonds have been created to fund projects that have positive environmental and/or climate benefits.

5) Environmental, social and governance (ESG) factors: there is growing evidence that suggests that ESG factors, when integrated into investment analysis and portfolio construction, may offer investors potential long-term performance advantages. As a result, there is a need to understand how ESG metrics can be strengthened to ensure maximum impact based on real-time data and information. In particular, how can the ESG performance of a company be calculated on the basis of actual environmental and social impacts in a transparent and robust way.

6) Supply chain transparency: there is a tremendous opportunity to use emerging technologies, such as blockchain, for supply chain management in a manner that would permit companies to offer consumers assured information on the Environment, Social and Governance (ESG) performance of products. The consumer would have absolutely certainty on the supply chain and authenticity of the product. In addition, there is high potential for the non-commercial aspects of these data to be potentially shared.

D) Business models

There is a need to understand the range of business models in the digital economy that can support the operationalisation of a digital ecosystem for environmental data. It is likely that the ecosystem will need to employ multiple business models which engage the private sector, public sector, public-private partnerships and finally non-profits toward the provisioning of data, algorithm and insight as global public goods. In particular, the following business models offer interesting potential opportunities:

1) Subscription Model (Netflix, Apple Music, New York Times): taking a product or service that is traditionally purchased on an ad hoc basis, and locking-in repeat customers by charging a subscription fee for continued access to the product/service.

2) Pay as you go model (Kindle, online journals, Mobility): users pay only for services which are used. In some cases, users also pay an annual membership fee. This also includes micropayments which is a kind of transaction is used to access a certain type of content, which could be an article on a webpage, a song, or the next level in a video game.

3) Freemium/Premium Model (Spotify, LinkedIn, Dropbox, Skype, Coursera): users get free access to a basic service or product but must pay an upgrade fee to access advanced premium features, or versions without embedded advertising.

4) The Free Model (Google, Facebook): the model involves offering consumers a 'free' product or service and sells their behaviour data and consumer preferences to different businesses.

5) Marketplace Model (eBay, iTunes, App Store, Uber, AirBnB): provides a digital marketplace that brings together buyers and sellers directly, in return for a transaction or placement fee or commission.

6) Access-over-Ownership Model (Zipcar, Peerbuy, AirBnB): providing temporary access to goods and services traditionally only available through purchase. Includes 'Sharing Economy', which takes a commission from people monetising their assets (home, car, capital) by lending them to 'borrowers'.

7) Cooperative Model (Waterwatch Cooperative): an autonomous association of persons united voluntarily to meet a specific need through a jointly-owned and democratically-controlled enterprise.

8) On-Demand Model (Uber, Operator, Taskrabbit, cloud services from Amazon, Microsoft): monetises time and sells instant-access to a product or service at a premium.

9) Ecosystem Model (Apple, Google, Microsoft Office): sells an interlocking and interdependent suite of products and services that increase in value as more are purchased. Creates consumer dependency.

10) Crowd-sourcing model (99Designs, Fiverr): taps into the collective intelligence and experience of the crowd to complete business transactions on the basis of competitive bidding.

11) Crowd-funding model (Kick starter): funding a project or venture by raising small amounts of money from a large number of people. Crowdfunding offers a forum for anyone who has an idea to pitch it to potential investors in exchange for a reward, profits from the future product, or an equity stake in the company.

12) Initial coin offering (Ethereum, MobileGo): the cryptocurrency equivalent to an Initial Public Offering (IPO) in the mainstream investment world. A company looking to create a new coin, app, or service launches an IPO. Investors hope that the token will perform exceptionally well into the future.

13) Open Access (Wikipedia): refers to any type of access for which no subscription or payment is necessary. This model is most often used to offer educational, scientific, academic and other public good materials.

14) Non-commercial use model (Key Biodiversity Areas Partnership): generates global public good data which is freely offered to public institutions but sold to commercial firms to maintain the cost of collection and processing.

15) Derivative product rights model (Descartes Labs): insights from raw private and public data are extracted and sold as new derivative products. The intellectual property (IP) of the original input data does not change hands, and instead a new derivative product is created with new IP conditions and value is created, captured and shared as a new market opportunity for the data provider. Examples of this include using public and commercial satellite and weather data to create crop production forecast, measures of industrial activity such as construction rates on a national scale, or measures of emissions tied to an asset class such as Oil and Gas or coal supply chains.

6. CONCLUSIONS

Developing a digital ecosystem for the environment that can be used for better policy intervention and environmental action will require a transformation for citizens, governments, the private sector and intergovernmental organisations to collect and share data, process data and create analytical insights and information. This transformation will be underpinned by a need to ensure transparency, accountability and comparability of global environmental data while at the same time protecting privacy and stimulating innovation and investment in data. Science-policy-business partnerships for innovative data technologies and digital solutions that accelerate the implementation of the Sustainable Development Goals and the Multilateral Environmental Agreements are a foundation for ensuring that data is collected, processed and used to develop insights covering a range of environmental issues, is inclusive in terms of geographic coverage, and provides insights to small communities as well as at the global level. The following are pre-conditions for moving toward a functional digital ecosystem for the environment:

Citizens must be engaged through:

1) Access to local, relevant data: applications and web-services should be developed to provide citizens with increasing access to local data about environmental change. Citizens are in the best position to use data and information to improve their own lives, communities and natural environment. However, citizens are often not aware of how to access digestible information which allows them to make informed decisions. The effectiveness of a digital ecosystem for the environment will rely on changing the way people interact with data and information.

2) Data feedback: citizens need to be engaged in both accessing data and contributing data to national and global data ecosystems. Operational, real time mechanisms for citizens to contribute information including data collection and usability comments should be readily available.

3) Organisational support: citizen science organisations and other community-based organisations must use data and insights to demonstrate gaps in terms of environmental protection, pollution and environmental policy in order to hold governments and companies more accountable.

4) Privacy and data sharing: citizens need to be informed of issues related to data privacy and have control over sharing their own data. This requires a high standard of transparency and functionality with interfaces so that users know what information is public and how to choose what is private vs. public. Many users may need to be educated in order to have full control over data sharing.

5) Decision-making information: citizens should have access to information which allows them to make better decisions related to their own consumption, for example, recording preferences related to preferring sustainable products, information related to the carbon or ecological footprint of different goods and services and access to information on the supply chain of certain products (e.g. for validation that a product is fair trade). This information should be coupled with actionable changes citizens can make to adapt their decisions to consumption information. This includes providing alternative sustainable options when possible.

Countries must create a culture of data use, innovation and data governance for national ecosystems:

1) Data policies: adopt free, full, and open data policies for the environment which fosters innovation, ensures privacy protection and facilitates data sharing, including coverage of all environmental data that are collected or financed through public funds. Consider requirements for companies to disclose on an annual basis metrics on the volume and types of data sets they are collected together with related processing and analytics technologies to help identify potential data and technology monopolies.

2) Monitoring and implementation: develop a set of critical environmental data sets that can be used to monitor progress toward the SDGs, the implementation of the Multilateral Environmental Agreements as well as contextual and emerging environmental issues over time.

3) Data availability and quality: establish comprehensive and inter-disciplinary environmental monitoring systems (including citizen science, earth observations and traditional data collection as well as global data products) to improve data availability timeliness, comparability, geospatial coverage and quality of critical environmental data sets.

4) Data capability: support the development of a national environment information system in the cloud to bring data from ministries, localities and non-governmental and private sector organisations together in a way that promotes interoperability, spatial referencing, quality, integrity and terms of use.

5) Open data and open software: ensure fair, and where possible, open electronic access to environmental data and the infrastructure needed for analysis, visualisation and communications. Open source software solutions for the aggregation, analysis, visualisation and communication of environmental data may have additional value for dissemination of data and information.

6) Data sharing technology: engage community organisations, municipalities and sub-national stakeholders in the collection and analysis for environmental data, including through utilising technologies and apps for sharing data and scientific discoveries (e.g. citizen science applications).

7) Data integration: enhance integrated use and analysis of environmental data from various sources (smart devices, mobile applications, environmental monitoring and research) as well as timeseries data (both statistical and geospatial).

8) Statistical data standards: use existing statistical standards such as the Framework for the Development of Environment Statistics, the System of Environmental Economic Accounting and SDG methodologies.

9) Geospatial data standards: employ common data standards, where possible, such as SDMX, W3C, ISO and OGC processes, as well as the existing open geospatial standards for Earth observations and emerging work on the SpatioTemporal Asset Catalog (STAC), the Open Data Cube (ODC) and the interfaces to share Analysis Ready Data (ARD).

Private sector contribution and data sharing

1) Data reporting: ensure that corporate sustainability reporting of technology firms mechanisms provide a framework for monitoring the impact of companies toward SDGs. This can be connected to the work of the Global Reporting Initiative.

2) Training: promote a culture of sustainability and valuing the environment, including through rolling out new training programmes for global ethics and value frameworks. This should include training on how to understand and use data for sustainability and environmental valuation.

3) Global data sharing: a new social contract between companies, governments and citizens is required where mutual obligations and responsibilities are spelled out. The cost of doing business anywhere in the world should be the release of relevant non-commercial data that can be used to measure SDG progress.

4) Global public goods: where technology firms and other private sector actors offer global public good platforms, the underlying business model should be disclosed so that public sector users fully understand the terms of use, risks, dependencies and trade-offs.

5) Data capability: design commercial ecosystems that are fully inter-operable with other private and public ecosystems as well as open source software where data can flow freely and not be restricted to a proprietary format.

6) Revenue sharing: explore ways for revenue sharing when public sector data is used to generate private sector profits. For example, if public sector data is used to train AI algorithms or public in-situ data is used to verify commercial earth observation data,

7) Technology sharing: identify mechanisms where technological advancements and technical expertise in the private sector can be shared with the public sector.

The UN can play a role to incubate and develop a global digital ecosystem:

1) Convening stakeholders and developing consensus: convening governments, private sector organizations, non-governmental, citizen science and community-based organizations, academia and other stakeholders to develop consensus and encourage commitments around data sharing, data privacy, data use, ethics and values frameworks and principles and other elements of a digital ecosystem for the environment.

2) Sharing best practices and experiences: propose and share technological solutions for the use of environmental data in ways that allow countries to produce results that inform the targets established in the Sustainable Development Goals and the Multilateral Environmental Agreements, based on national circumstances and on the countries own expertise.

3) Data analysis and visualization: identify priorities in terms of developing insights for environmental priorities and emerging environmental issues and form partnerships to ensure that priorities are kept under review. This includes providing access to data and data visualisation, for example the World Environment Situation Room powered by MapX is UN Environment's initiative for ensuring that key environmental data and insights can be visualised and accessed in an integrated manner (spatial and statistical data) (UNEP 2019).

4) Data standards: promote open data and open source tools, including through implementing open data policies within the UN System and supporting the development of open source tools for accessing and visualising data, including geospatial data, such as MapX.

5) Capacity building: create a strategy for addressing capacity gaps in collaboration with other intergovernmental organisations and donors, including through ensuring that collecting and using environmental data is integrated within the UN Common Country Assessments (CCA) and UN Development Assistance Frameworks (UNDAF) which guide the work of the UN at the national level. In particular, the country offices of UNDP could be leveraged for capacity building on data collection and use.

6) Promote data use in international planning and policy: align the programme of work of UN Environment, as the UN entity responsible for the environmental dimension of sustainable development, with priority needs identified through leveraging best available statistical and spatial data in planning, policy-making and impact monitoring.

7) Data integration across the UN: need to connect different UN ecosystems and to leverage these in support of national level analysis, prioritisation, planning and monitoring within the CCA/UNDAF

8) Open data funding: finance open data, open source software, and open algorithms that contribute to a set of global public goods.

Innovative partnerships are the foundation for a global digital ecosystem for the environment:

1) Data standards for the global public good: the overall outcome of these partnerships should be increased accessibility and use of environmental data that are established on a planetary level as a global public good.

2) Data integration from across the public and private sector: the UN is in a position to collaborate with a broad range of data providers to bring data into a global digital ecosystem for the environment. By providing access to data, progress towards achieving Agenda 2030 is complemented by full environmental transparency. In addition to global and national level data, environmental performance data is routinely disclosed by private sector operators across different sectors, embedding environmental considerations within the responsible sourcing of natural resources and facilitating access to information for consumers.

3) Using data and insights to encourage partnerships toward achieving the SDGs: public-private partnerships that seek to solve specific problems linked to SDGs informed by current data. These specific problems can be continually updated with continually updating data – information on specific SDG issues will be more time-sensitive than before. Additionally, data may be used to identify potential issues in terms of potential social and environmental impact.

4) Applications of data: define, document and share use cases and market applications of a digital ecosystem of environmental data, analytics and insights through creating market places for matching demand and supply, problem and solution in the environmental space. Current data to update economic trends in real time can change the cycle of reactive policies and revolutionise economic analysis.

Annex I: Stakeholders consulted

Organization
Accenture London
ADEC Innovations
African Academy
AfroChampions
Agence Française De Développement
African Ministerial Conference on the Environment (AMCEN)
Argonne National Laboratory
Belmont Forum Secretariat
Bottle Dream
Bureau de Recherches Géologiques et Minières (BRGM)
Climate & Clean Air Coalition
Centre National d'Etudes Spatiales (CNES)
Commissariat à l'Energie Atomique (CEA)
Conseil Présidentiel pour l'Afrique
Dataiku, AI Labs
Descartes Labs
Dream, Tunisia
Earth Genome
Ecosphere Capital Limited
ENEL
Estonia Ministry of Environment
EU Joint Research Centre (JRC)
European Commission
European Space Agency
French Ministry for Europe and Foreign affairs
French National Research Institute for Sustainable Development/ IRD
GE Renewable Energy
Group on Earth Observations (GEO) Secretariat
Global Biodiversity Information Facility (GBIF)
Google Earth Engine
UNEP GRID-Geneva
IBM
INRA
Institute for European Environmental Policy (IEEP)
Institute of Remote Sensing and Digital Earth, CAS
Inter-American Institute
International Chamber of Commerce (ICC)
International Fertilizer Association
International Institute for Research and Development
International Science Council
International Union for the Conservation of Nature (IUCN)
Intergovernmental Panel on Climate Change (IPCC)
Institut de recherche pour le développement (IRD)

MapX
Ministère de la Transition écologique et solidaire
Ministry of Artificial Intelligence, UAE
Ministry of Foreign Affairs, France
MyHeat / University of Calgary
NASA Ames Laboratory for Advanced Sensing
Norwegian University of Science and Technology
Leonardo DiCaprio Foundation (LDF)
Planet Labs
Plast'if
Price Waterhouse Coopers (PWC)
Qwant
Resallience/ Vinci
Secretariat of the International Resource Panel (IRP)
SFR Racines
SNCF
Soarability Technologies
Society of Entrepreneurs for Ecology (SEE) Foundation
SolarKiosk
Startupbrics
The Economic Times
The Foundation for Research on Biodiversity
The Future Society
Thomson Reuters Corporation
Triton Foodworks
UN Development Programme (UNDP)
UN Environment (UNEP)
UN Global Pulse Labs
Université Paris Dauphine et CNRS
University of California, Berkeley
University of Edinburgh
Utrecht University
Vice President for Veterinary Medicine and Natural Sciences, Professor in Remote Sensing
Wild Immersion
World Meteorological Organization (WMO)
Woodrow Wilson International Center for Scholars
World Conservation Monitoring Center (WCMC)
World Economic Forum (WEF)
Xi'an Jiaotong-Liverpool University (XJTLU)
X-Prize

Annex II: Platforms hosting environmental data, algorithms and insights reviewed

Theme	Name	Website	Organization	Powered by
Multi-thematic	Google Earth Engine	https://earthengine.google.com/	Google	Google Earth Engine
	Environmental Situation Room	https://environmentlive.unep.org/situation	UNEP	MapX
	Resource	https://resourcewatch.org/	WRI	Google Earth
	Trends.Earth	http://trends.earth/docs/en/index.html	Conservation International	via QGIS desktop application
	UN Global Platform for Official Statistics	https://www.officialstatistics.org/	UN	/
	UN Spatial Data Infrastructure initiative (UNSDI)	http://www.unsdi.nl/	UN	/
	Future Earth	http://medialab.futureearth.org/	Future Earth, Globaïa and the International Council for Science	(Anthropocene: Google)
	Earth Map	https://earthmapdemo.info	FAO	Google Earth Engine
	Open Foris / Collect Earth	http://www.openforis.org/tools/collect-earth.html	FAO	Google Earth Engine
	CASEarth (Big Earth Data Platform)	http://www.casearth.com/	Chinese Academy of Sciences	/
	Earth Explorer	https://earthexplorer.usgs.gov/	USGS	Google
	SDG Data Hub	http://www.sdg.org/	UN	ESRI
	Global Pulse Labs	https://www.unglobalpulse.org/pulse-labs	UN	/
	MapX	https://www.mapx.org	UN	MapX
Climate	ClimateSeed	https://www.climateseed.com/		/
	Space Climte Observatory	https://www.spaceclimateobservatory.org/	CNRS, Meteo France, IRD, CNES, Chinese Space Agency, Marroco	/
	Copernicus climate data store	https://climate.copernicus.eu/	EC, Copernicus, ECMWF	/
	Moja	https://moja.global/	Linux fundation	/
	Climate engine	http://climateengine.org/	University of Idaho, DRI, Google Earth Engine	Google
	VAMPIRE	http://pulselabjakarta.id/vampire/	WFP, FAO	Carto DB

Water	SDG 661 (Surface Water Monitoring)	https://www.sdg661.app	UNEP, Google Earth Engine, JRC	Google
	Gobal Surface Water Explorer	https://global-surface-water.appspot.com/	Google Earth Engine, JRC	Google
	Flood and Drought Monitor	http://www.flooddroughtmonitor.com/home	UNEP and DHI	Google
	Transboundary Waters Assessment Programme	http://twap-rivers.org/indicators/	UNEP	Open Geosuite
	Water Peace and Security Partnership	https://www.un-ihe.org/water-peace-and-security-partnership	UNESCO	/
Forests	Global Forest Watch	https://www.globalforestwatch.org/	WRI	Google
	Global Forest Resources Assessment	http://www.fao.org/forestry/en/	FAO	Open Geosuite
	IMPACT Tool Box	https://webgate.ec.europa.eu/fpfis/mwikis/impacttoolbox/index.php/Impact_Toolbox_User_Guide	JRC	Google
Biodiversity	Global Biodiversity Information Facility (GBIF)	https://www.gbif.org/	network of research centers	MapBox
	Biodiversity Indicators Partnership (BIP)	http://bipdashboard.natureserve.org/bip/SelectCountry.html	Consortium of various organization	ESRI
	UN Biodiversity Lab	https://www.unbiodiversitylab.org/	UNEP, UNDP	MapX
	NatureMap Project	Under Development	Norway's International Climate and Forests Initiative	/
	IUCN Red List of Threatened Species	https://www.iucnredlist.org/resources/spatial-data-download	IUCN	ESRI
	IUCN Red List of Ecosystems	https://iucnrle.org/	IUCN	/
	Map of Life (MOL)	https://mol.org/	Yale University	Google
Protected Areas	Protected Planet	https://www.protectedplanet.net/	UNEP WCMC	MapBox
	Digital Observatory for Protected Areas (DOPA)	https://dopa-explorer.jrc.ec.europa.eu/dopa_explorer	EU JRC	Open GeoSuite
Natural Hazards	Global Risk Data Platform (PREVIEW)	https://preview.grid.unep.ch/	UNEP GRID / UNISDR	Open GeoSuite
	ECO-DRR Opportunity Mapping	Under development	UNEP	MapX
Chemicals	Global Chemicals Observatory	Under development	UNEP	MapX
Marine	Global Fishing Watch	https://globalfishingwatch.org/	WRI	Google Earth Engine
	Global Ocean Observing System	http://www.goosocean.org/	IOC-UNESCO’s	/

Earth Observation	Sentinal	https://apps.sentinel-hub.com/eo-browser/	EU	Open GeoSuite
	Planet	https://www.planet.com/	Planet Labs	/
	Landsat	https://landlook.usgs.gov/viewer.html	US	ESRI
	GEOSS	http://www.geoportal.org/	GEO	Various: Open GeoSuite, ESRI, Carto, Mapbox
	Satelligence	https://satelligence.com/	Satelligence	/
	Descartes Labs	https://www.descarteslabs.com/	Descartes Labs	Descartes Lab
	Earth on AWS	https://aws.amazon.com/earth/	Amazon Web Services	AWS
	Geospatial Big Data Platform (GDBX)	https://www.digitalglobe.com/platforms/gbdx	Digital Globe	AWS
	Radiant Earth	https://www.radiant.earth/	Radiant Earth	/
	Open Data Cube	https://www.opendatacube.org/	Open Data Cube	/
	Earth now	https://earthnow.com/	Earth Now	/
	Earth Genome	https://www.earthgenome.org/	Earth Genome	ESRI, Planet Lab
	TERRSET	https://clarklabs.org/terrset/	ClarkLabs	Google? to be confirmed
	Copernicus Open Access Hub	https://scihub.copernicus.eu/dhus/#/home		Open GeoSuite
AI	Artifical Intelligence for Ecosystem Services	http://aries.integratedmodelling.org/	University of Vermont, Earth Economics, Conservation International	separate software (k.Lab)
	AI for Earth	https://www.microsoft.com/en-us/ai/ai-for-earth	Microsoft	ESRI and AZURE
	IBM Green Horizons	https://www.research.ibm.com/green-horizons/interactive/	IBM	/
	Picterra	https://picterra.ch/	Picterra	/

References

Alipay (2019). Trust makes it simple. [https://intl.alipay.com/ Accessed: 18 February 2019.

APA Style (2019). What is a digital object identifier, or DOI? [APA Style https://www.apastyle.org/learn/faqs/what-is-doi Accessed: 18 February 2019.

Baffour, B., King, T. and Valente, P. (2013). The Modern Census: Evolution, Examples and Evaluation. 11. https://espace.library.uq.edu.au/data/UQ_319099/UQ319099OA.pdf?Expires=1550673600&Signature=ewgZPBOfHibzCEZsA8eB3rSq9y22ZSmKkG80riSUOuunZGR9G1PL0utm3w519Ir4MgwsOGPXnFN~dVStDXFmoYFzvu9I716ftV9PJBagu30XuW0k6L4M~GkS7pPtz9LgMywfSntIQUZVmqh1mSHANEgj26o2S357bmKXCYTmK46kAHIK5DFTgOtF2mAVTXfHkwLJ0UBZOR2GlK0SOz3ynjs6mJU2cjBNVAVRrRnQKs2riVzui1~iWAP~Ugjhl4vF1cQKVfIPAB8XMGrssdFJStm5lLYa6BENsNvqQLkFJHZNMPpHTOlT5g5dGf1PN9ouL4FGE9f~f68s1bRePtJWPw__&Key-Pair-Id=APKAJKNBJ4MJBJNC6NLQ.

Bandura, I. (2018) *Sludge River* https://unsplash.com/photos/ui9JgZZlUno. Accessed 5 March 2019.

Chapron, G. (2017). The environment needs cryptogovernance https://www.nature.com/news/the-environment-needs-cryptogovernance-1.22023.

Citizen Science Association (2019). The Power of Citizen Science. [https://www.citizenscience.org/.

Columbus, L. (2016). Roundup Of Internet Of Things Forecasts And Market Estimates, 2016. [https://www.forbes.com/sites/louiscolumbus/2016/11/27/roundup-of-internet-of-things-forecasts-and-market-estimates-2016/#17d8afac292d Accessed: 18 February 2019.

Contributors to the Decentralized Identifiers (2019). Decentralized Identifiers (DIDs) v0.11. [The World Wide Web Consortium https://w3c-ccg.github.io/did-spec/ Accessed: 18 February 2019.

Desjardins, J. (2018). Visualizing The World's 20 Largest Tech Giants. [https://www.visualcapitalist.com/visualizing-worlds-20-largest-tech-giants/ Accessed: 21 February 2019.

European Space Agency (2018). Sentinel Overview https://m.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4.

Evans, D. (2016). How Big Data Can Enable a Transparent Marketplace for Consumer Goods https://sustainablebrands.com/read/cleantech/how-big-data-can-enable-a-transparent-marketplace-for-consumer-goods.

FIDO Alliance (2018). FIDO TechNote: The Growing Role of Token Binding. [FIDO Alliance https://fidoalliance.org/fido-technote-the-growing-role-of-token-binding/ Accessed: 18 February 2019.

Food and Agriculture Organization of the United Nations (2019). World Programme for the Census of Agriculture. [http://www.fao.org/world-census-agriculture/en/ (Accessed: 19 February 2019).

Fortney, L. (2019). Blockchain, Explained. [Investopedia https://www.investopedia.com/terms/b/blockchain.asp (Accessed: 18 February 2019).

Gelenbe, E. and Caseau, Y. (2015). The Impact of Information Technology on Energy Consumption and Carbon Emissions. Ubiquity.

Global Fishing Watch (2019). Global Fishing Watch. https://globalfishingwatch.org/.

Global Forest Watch (2019). Global Forest Watch. https://www.globalforestwatch.org/.

Global Reporting Initiative (2016). Sustainability Disclosure Database. http://database.globalreporting.org/.

Gupta, A. (2009). Data Provenance. Encyclopedia of Database Systems. https://link.springer.com/referenceworkentry/10.1007%2F978-0-387-39940-9_1305.

Handayani, W. and Prayogo, R.A. (2017). Green Consumerism : an Eco-Friendly Behaviour Form Through The Green Product Consumption and Green Marketing. Sinergi 7(2). https://www.researchgate.net/publication/319601257_Green_Consumerism_an_Eco-Friendly_Behaviour_Form_Through_The_Green_Product_Consumption_and_Green_Marketing.

Henke, N., Bughin, J., Chui, M., Manyika, J., Saleh, T., Wiseman, B. et al. (2016). The Age of Analytics: Competing in a Data-driven World. https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Analytics/Our%20Insights/The%20age%20of%20analytics%20Competing%20in%20a%20data%20driven%20world/MGI-The-Age-of-Analytics-Full-report.ashx.

Herman, A. (2018). The War For The World's 5G Future https://www.forbes.com/sites/arthurherman/2018/10/17/the-war-for-the-worlds-5g-future/#7b51d3491fe5.

iNaturalist (2017). Year in Review 2017. [https://www.inaturalist.org/stats/2017.

iNaturalist (2019a). Observations. [https://www.inaturalist.org/observations?place_id=any.

iNaturalist (2019b). How it Works. [https://www.inaturalist.org/ Accessed: 18 February 2019.

International Monetary Fund (2017). International Monetary Fund Data. https://www.imf.org/en/Data.

Internet World Stats (2018). World Internet Usage and Population Statistics. [https://www.internetworldstats.com/stats.htm Accessed: 18 February 2019.

Jacobs, C. (2016). Data quality in crowdsourcing for biodiversity research: issues and examples. In European Handbook of Crowdsourced Geographic Information. Ubiquity Press. 75-86. https://www.geog.uni-heidelberg.de/md/chemgeo/geog/gis/europ_handb_of_crowds_geog_inf_chapter6_jacobs.pdf.

Knight, M. (2017). Data Curation 101: The What, Why, and How. [Dataversity https://www.dataversity.net/data-curation-101/ Accessed: 20 February 2019.

Knight, M. (2017). What is Metadata? [Dataversity https://www.dataversity.net/what-is-metadata/ Accessed: 18 February 2019.

Laybourn-Langton, L., Rankin, L. and Baxter, D. (2019). This is a Crisis: Facing up to the Age of Environmental Breakdown. London. https://www.ippr.org/research/publications/age-of-environmental-breakdown.

Moen, T.L. (2017). People record species like never before. [The Norwegian Biodiversity Database, https://www.artsdatabanken.no/Pages/229530 Accessed: 22 February 2019.

National Science Board (2018). Outputs of S&E Research: Publications. In 2018 Indicators Report. Alexandria: National Science Foundation. chapter Chapter 5: Academic Research and Development. 112. https://www.nsf.gov/statistics/2018/nsb20181/assets/968/academic-research-and-development.pdf

Open Data Cube (2019). An Open Source Geospatial Data Management & Analysis Platform. [https://www.opendatacube.org/ Accessed: 18 February 2019.

Open Geospatial Consortium (2019a). About OGC. [http://www.opengeospatial.org/about Accessed: 18 February 2019.

Open Geospatial Consortium (2019b). Introduction to WMS. [http://www.opengeospatial.org/standards/wms/introduction Accessed: 18 February 2019.

Open Geospatial Consortium (2019c). Web Feature Service. [https://www.opengeospatial.org/standards/wfs Accessed: 18 February 2019.

Open Geospatial Consortium (2019d). Web Coverage Service. [https://www.opengeospatial.org/standards/wcs Accessed: 18 February 2019.

Open Geospatial Consortium (2019e). Web Processing Service. [https://www.opengeospatial.org/standards/wps Accessed: 18 February 2019.

Organisation for Economic Co-operation and Development (2016). Blended Finance. [http://www.oecd.org/development/financing-sustainable-development/development-finance-topics/blended-finance.htm.

Parietti, M. (2018). The Top 10 Technology Companies (AAPL, GOOGL). [Investopedia https://www.investopedia.com/articles/markets/030816/worlds-top-10-technology-companies-aapl-googl.asp Accessed: 19 February 2019.

Qin, L. (2015). 'Blue Sky' app to get China's public thinking about solutions to pollution crisis. [https://www.chinadialogue.net/article/show/single/en/7870--Blue-Sky-app-to-get-China-s-public-thinking-about-solutions-to-pollution-crisis Accessed: 18 February 2019.

Ripple, W.J., Wolf, C., Newsome, T.M., Galetti, M., Alamgir, M., Crist, E. et al. (2017). World Scientists' Warning to Humanity: A Second Notice BioScience 67(12), 1026-1028. https://doi.org/10.1093/biosci/bix125.

Saboor, A. (2013). The Data Attribution. Berlin: Freie university Berlin. http://open-data.fokus.fraunhofer.de/wp-content/uploads/sites/3/2013/11/Saboor_The-Data-Attribution.pdf.

Sawyers, P. (2017). 5 billion people now have a mobile phone connection, according to GSMA data. [https://venturebeat.com/2017/06/13/5-billion-people-now-have-a-mobile-phone-connection-according-to-gsma-data/ Accessed: 18 February 2019.

Schwab, K. (2016). The Fourth Industrial Revolution. World Economic Forum. https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab.

Scott, C. (2005). Measuring Up to the Measurement Problem. London School of Economics. https://paris21.org/sites/default/files/1509.pdf.

Statista (2018). Number of apps available in leading app stores as of 3rd quarter 2018. [https://www.statista.com/statistics/276623/number-of-apps-available-in-leading-app-stores/ Accessed: 18 February 2019.

Statistical Data and Metadata eXchange (2018). What is SDMX? [https://sdmx.org/?page_id=3425 Accessed: 18

February 2019.

Swedish LifeWatch (2017). Swedish LifeWatch – a national e-infrastructure for biodiversity data. ArtDatabanken SLU. https://www.slu.se/globalassets/ew/subw/lifewatch/publikationer/slw-summary-report-web.pdf.

Team eBird (2018). 500 million eBird records. [eBird https://ebird.org/news/500-million-ebird-records Accessed: 22 February 2019.

Techopedia (2019). Data Democratization. [https://www.techopedia.com/definition/32637/data-democratization Accessed: 18 February 2019.

The Secretary-General's Independent Expert Advisory Group on a Data Revolution for Sustainable Development (2014). A World That Counts: Mobilising The Data Revolution for Sustainable Development. http://www.undatarevolution.org/wp-content/uploads/2014/12/A-World-That-Counts2.pdf.

The World Bank (2000). Managing Records as the Basis for Effective Service Delivery and Public Accountability in Development. http://siteresources.worldbank.org/EXTARCHIVES/Resources/Core%20Principles.pdf.

Thomson Reuters (2018). Environmental, Social and Corporate Governance - ESG. [https://developers.thomsonreuters.com/content/environmental-social-and-corporate-governance-esg.

Union of Concerned Scientists (2018). UCS Satellite Database. https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.XGwQx-gzbIV Accessed 18 February 2019.

United Nations (2015). Paris Agreement. https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

United Nations (2015). UN Data Innovation Lab. [https://data-innovation.unsystem.org/.

United Nations (2018a). Tier Classification for the SDG Indicators. New York, NY. https://unstats.un.org/sdgs/files/Tier%20Classification%20of%20SDG%20Indicators_31%20December%202018_web.pdf.

United Nations (2018b). Secretary-General's High-level Panel on Digital Cooperation http://www.un.org/en/digital-cooperation-panel/.

United Nations Environment Programme (2019). Environment Live [https://environmentlive.unep.org/.

United Nations General Assembly (2015). Transforming our world: the 2030 Agenda for Sustainable Development. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E.

United Nations Global Pulse (2018). United Nations Global Pulse: Harnessing big data for development and humanitarian action. [https://www.unglobalpulse.org/.

United Nations Office for Disaster Risk Reduction (2015). Sendai Framework for Disaster Risk Reduction 2015-2030. Sendai. https://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf.

United Nations Statistics Division (2019). UN Global Working Group for Big Data. [https://unstats.un.org/bigdata/.

United Nations, Framework Convention on Climate Change (1992). United Nations Framework Convention on Climate Change. https://unfccc.int/resource/docs/convkp/conveng.pdf. FCCC/INFORMAL/84 GE.05-62220 (E) 200705.

World Bank (2019). World Bank Open Data. https://data.worldbank.org/.

Worth, D. (2014). Internet of Things to generate 400 zettabytes of data by 2018. [https://www.v3.co.uk/v3-uk/news/2379626/internet-of-things-to-generate-400-zettabytes-of-data-by-2018 Accessed: 18 February 2019.