COMMENTS

DIGITAL TECHNOLOGY AND THE ENVIRONMENT

by Wayne S. Balta, Jacob Dencik, Daniel C. Esty, Scott Fulton, and Terry F. Yosie

Wayne S. Balta is Vice President of Corporate Environmental Affairs and Product Safety and Chief Sustainability Officer at IBM. Jacob Dencik is Global Economic Research Leader at the IBM Institute for Business Value. Daniel C. Esty is Hillhouse Professor of Environmental Law and Policy at Yale University. Scott Fulton is President of the Environmental Law Institute. Terry F. Yosie is Former President and Chief Executive Officer at the World Environment Center.

In September 2020, IBM convened a round table of experts and stakeholders to discuss the potential of data and digital technologies to advance environmental sustainability. More than 25 participants representing government, the private sector, academia, and not-for-profit organizations from around the world attended the event,[1] and explored the opportunities and challenges associated with using data to further environmental objectives. This Comment is adapted from the round table report.

I. Environmental Sustainability—The Next Data Frontier

Our physical environment is a rich source of data. Rivers flow with it, storms swirl with it, soil teems with it. It can inform our daily lives, our interaction with the natural world, and has direct and indirect implications for our economic activity. In fact, data describing our physical environment, and the information and insight drawn from it, have underpinned all human progress.

Data have dramatically changed many realms of human activity, from how sports teams select players to how businesses market their goods and services. We now have the opportunity to bring the environmental realm into the mainstream of the digital age by tapping its bounty of data, making sense of it, and sharing it broadly.

In many ways, the emergence of what is commonly called "big data"—large data sets characterized by the speed at which they are generated, often in real time, and their variety and granularity—should merely reflect an extension of how we engage with our natural environment. Nature is big data. It offers an unprecedented opportunity for scientific progress and innovations that can address our most pressing environmental problems and improve our living conditions (see Box 1).

In fact, the environment is the next data frontier. While businesses and societies have already been disrupted by the advent of big data and digital technologies, the physical environment presents the next big opportunity, not least as a result of technologies like Internet of Things, which is generating 400 zettabytes of new data every year.[2]

1. Participants included Solomon Assefa, Vice President (VP), Future of Climate and Impact Science, IBM Research Division; Wayne Balta, VP Corporate Environmental Affairs and Product Safety and Chief Sustainability Officer, IBM Corp.; C.B. Bhattacharya, Professor and Chair of Sustainability and Ethics and Director, Center for Sustainable Business, University of Pittsburgh; Anne Bowser, Deputy Director, Science and Technology Innovation Program and Director of Innovation, Wilson Center; Dan Chenok, Director, IBM Center for the Business of Government, IBM Client Centers; Jacob Dencik, Economic Research Leader, IBM Institute for Business Value, IBM Global Business Services; Edan Dionne, VP Environment, Energy, and Chemical Management Programs, IBM Corporate Environmental Affairs; Dan Esty, Professor, Yale University, and prior Commissioner of the Connecticut Department of Energy and Environmental Protection, as well as senior roles at U.S. Environmental Protection Agency (EPA); Scott Fulton, President, Environmental Law Institute, and prior General Counsel (and other senior roles) at EPA; Antonia Gawel, Head, Circular Economy and Innovation, World Economic Forum; James Gowen, Senior VP Global Supply Chain, and Chief Sustainability Officer, Verizon; Dan Greenbaum, President, Health Effects Institute; Kathryn Guarini, Chief Information Officer (CIO), IBM Corp.; Hendrik Hamann, Chief Scientist for Geoinformatics and PAIRS Geoscope, IBM Cloud and Cognitive Software; Neil Hawkins, President and Chief Operating Officer (COO) of Erb Foundation, and retired VP and Chief Sustainability Officer, Dow Chemical; Jacqueline McGlade, Professor at Strathmore University, former Chief Scientist at the United Nations Environment Programme (UNEP), and former Executive Director of the European Environment Agency; Guille Miranda, former Head of Corporate Social Responsibility, IBM Corp.; Richard Newell, President and Chief Executive Officer (CEO), Resources for the Future; Christopher Padilla, VP, Government and Regulatory Affairs, IBM Corp.; Janet Peace, Chief of Advisory Services, Bluesource LLC, previously Senior VP at Center for Climate and Energy Solutions; Bill Sanders, Dean, College of Engineering, Carnegie Mellon University; Larry Selzer, President and CEO, The Conservation Fund; Renee Wynn, retired CIO, National Aeronautics and Space Administration (NASA); Terry Yosie, former President and CEO, World Environment Center; Dave Zaharchuk, Research Director, IBM Institute for Business Value, Global Business Services; and Shereen Zorba, Head of Secretariat, United Nations Science-Policy-Business Forum on the Environment, UNEP.

2. David Jensen & Jillian Campbell, The Promise and Peril of a Digital Ecosystem for the Planet (2019), https://medium.com/@davidedjensen_99356/building-a-digital-ecosystem-for-the-planet-557c41225dc2.

Box 1. Definitions: Big Data, Data Governance

Big data refers to very large data sets that usually cannot be processed in a reasonable amount of time using standard software and computing. These data sets often require parallel processing and can include structured and unstructured information. Typically, the amount of data in these sets is enormous, of varied types, and is generated rapidly—and needs to be processed rapidly to be of value.

Concern arises because some of these big data sets contain sensitive information—healthcare data, for instance—that could easily be misused. Often, the power of big data is in combining seemingly unrelated data sets to tease out connections and correlations. For instance, healthcare data plus weather, location, and other environmental data taken together can yield unique insights and patterns. But how can we make sure sensitive data does not fall into the wrong hands, or is otherwise misused?

Data governance is one way to avoid this trap. In its simplest form, it refers to the norms, principles, and rules applied to managing different types of data. Data governance can apply at a very localized level—within an organization—to handle its data properly and maintain its integrity and usefulness at each stage of its life cycle. It can also apply to cooperation between organizations—how they will share data—and even countries. Data governance initiatives in the environmental space include the Environmental Data & Governance Initiative and the Environmental Data Initiative.*

* Environmental Data & Governance Initiative, *Home Page*, https://envirodatagov.org (last visited Apr. 7, 2021); Environmental Data Initiative, *Home Page*, https://environmentaldatainitiative.org (last visited Apr. 7, 2021).

More specifically, we face two opportunities. First, to collect and curate environmental data across government agencies, industry sectors, and nongovernmental organizations in a way that is open and accessible. Second, to turn that data into value and insight. So far, we have not capitalized fully on either opportunity.

This slow progress is striking, given the demonstrated transformative impact digitization can have on the environment. For example, every day, millions of people use traffic apps that tap real-time data to identify the fastest routes, avoid congestion, and reduce emissions. Weather apps are used to adjust heating and cooling of buildings, thereby reducing energy use and pollution.

Data from the environment is also ushering in new business models, such as those based on "sharing economy" or "circular economy" principles, which reconceptualize and alter the need for and use of physical resources and assets. It is also spurring innovations that would otherwise not be feasible. For example, smart thermostats and meters can lead to smarter pricing structures, while conserving energy and natural resources.

In addition, big data and digital technologies can help solve environmental problems in new ways through timelier, more geographically granular insight. Farmers, for example, armed with weather data and modeling software, can reduce water use, conserving both money and a precious natural resource.

Applying digital technologies to environmental data can also make it easier to manage environmental conditions and extend involvement in that management more broadly. This, in turn, helps inform better environmental policies and regulations—even change the way environmental decisions are made.

For example, bird migrations often cross multiple regions and borders and are difficult to predict. This makes conservation efforts and creating the right policies challenging. But using more than 20 years of radar data, one forecast model accounted for more than 80% of the variance in bird migration patterns. Armed with this understanding, conservation efforts could more effectively mitigate danger to migrations with more targeted, less disruptive policies.[3]

Moreover, environmental data and insights drawn from analysis of it have the potential to transform traditional regulatory approaches by mobilizing nongovernmental drivers for change. The private sector, civil society, and machine-aided control and correction systems can help drive needed change without the need for government intervention. These complementary drivers could greatly reduce the load for regulators and regulations.

For example, Geofinancial Analytics harvests and analyzes publicly available data on methane emissions from oil and gas operations.[4] It sells data analytics to mutual fund and hedge fund managers to enable their sustainability agendas and inform investor choice and influence. This insight can advance the financial sector's sustainability ambition while creating investor pressure to reduce methane leakage. This model illustrates how new digitally based governance approaches could operate without the hand of government. In some ways, they are potentially more powerful and efficient in driving change than traditional regulation because the lever being deployed is access to capital—business's life blood.

Also, if transparent and trusted, data and digital technologies promise to dramatically improve environmental accountability. If what is happening is knowable and transparently seen, this should allow regulation to be refocused away from process controls and toward measurable environmental conditions. If conditions are positive, this could lead to new flexibilities with respect to process management. On the other hand, if measurable conditions suggest problems clearly seen by relevant actors, then identifying and correcting the problem can happen at speeds impossible through conventional intervention models.

3. Jenna Tsui, *Using Big Data Technology for Environmental Protection*, Env't Protection, Mar. 25, 2020, https://eponline.com/Articles/2020/03/25/Using-Big-Data-Technology-for-Environmental-Protection.aspx?Page=1.
4. Geofinancial Analytics, *Home Page*, https://geofinancial.com (last visited Apr. 7, 2021).

In fact, making environmental data accessible and sharing it widely can break down barriers to collaboration, highlight areas of common interest, and facilitate open innovation. It can also help harness the collective intelligence of communities and private- and public-sector actors (see Box 2).

Box 2. PRISM: Tracking Plastic Waste and Recovery With Shared Data on Cloud

A significant obstacle in combating plastic waste is how to bring together the multitude of data that exists in a way that is verifiable, flexible, and actionable.

The Plastics Recovery Insight and Steering Model (PRISM) is a cloud-hosted data platform to help track plastic waste and recovery globally. It aims to serve as a single source of consistent, actionable data for NGOs, value chain participants, communities, regulators, and other organizations to improve waste management decisions and programs.

The platform will be designed to allow stakeholders to convene and unite various data sets. Areas of focus include plastic consumption and collection, plastic waste generated and leaked into the environment, waste management and recycling solutions, and more as the tool is expanded.*

*DeAnne Toto, Data Platform *Will Track Global Plastic Waste in the Environment*, Recycling Today, Dec. 15, 2020, https://www.recyclingtoday.com/article/ibm-platform-tracks-plastic-waste-environment/.

Augment this collective intelligence with digital technologies, and you can accelerate the pace of discovery and transformation at scale, altering our interaction with the environment at the micro and macro levels. Put plainly, the combination of data, digital tech, and collective intelligence can be the catalyst for a more environmentally sustainable future (see Figure 1 next page).

However, in many instances, environmental initiatives using big data and digital technologies have yet to reach the scale where local or even national economies are transformed toward a more environmentally sustainable trajectory. Why? Part of the reason may be the nature of environmental data.

II. Environmental Data Challenges

To call environmental data complex is an understatement—it includes data from the almost 5,000 satellites orbiting the earth, rapidly increasing drone operations, 20 billion scattered sensors capturing data in real time, as well as millions of records created by enthusiastic citizens on anything from bird sightings to the quality of air in their local neighborhoods. Not to mention underground well logs, soil characterization, underwater probes, point source air emissions, transportation emissions, wildlife biomonitoring, chemical signatures, and more. While we are rapidly becoming better at capturing the data, we continue to struggle with putting it to use. This is understandable: using environmental data poses many peculiar challenges.

Environmental data's wide range of different sources and many different forms, combined with the fact that it is not refined enough to be used in decisionmaking, indicates we need better strategies for data collection, normalization, and validation. The environment is not a uniform, single entity from which we obtain data, but rather a complex system of systems, comprising the geosphere, hydrosphere, biosphere, and atmosphere. Each of these aspects of the natural environment poses different challenges for using big data.

In addition, to understand relationships between human activity and the environment, core environmental data needs to be combined with other factors. Health, economic activity, demographics, and other data types can amplify the environmental data's usefulness. Accordingly, tapping into the potential of big data poses a massive integration challenge.

Moreover, environmental data are difficult to search. It generally requires context to understand and act on. At its most fundamental level, it takes spatial and temporal context to deduce physical relations driven by cause and effect.

The Jefferson Project at Lake George, New York, provides a concrete example of this challenge. In an attempt to understand the health of the lake and the impact of human activity on it, the collaborative research project is deploying connected sensors to make the lake "smart." But making sense of the raw data from those sensors—more than nine terabytes of data annually from 52 different multisensory platforms at the lake—requires multiple models and analytical approaches. Variables related to weather, water movement, chemical composition, flora, and fauna in and around the lake and tributaries must be corralled into multiple models: weather, runoff, salt, food-web, and circulation models, to name just a few.[5]

Accordingly, contextualization becomes a challenge as more data requires more computation and analysis. Making sense of the environmental data we collect is no small feat.

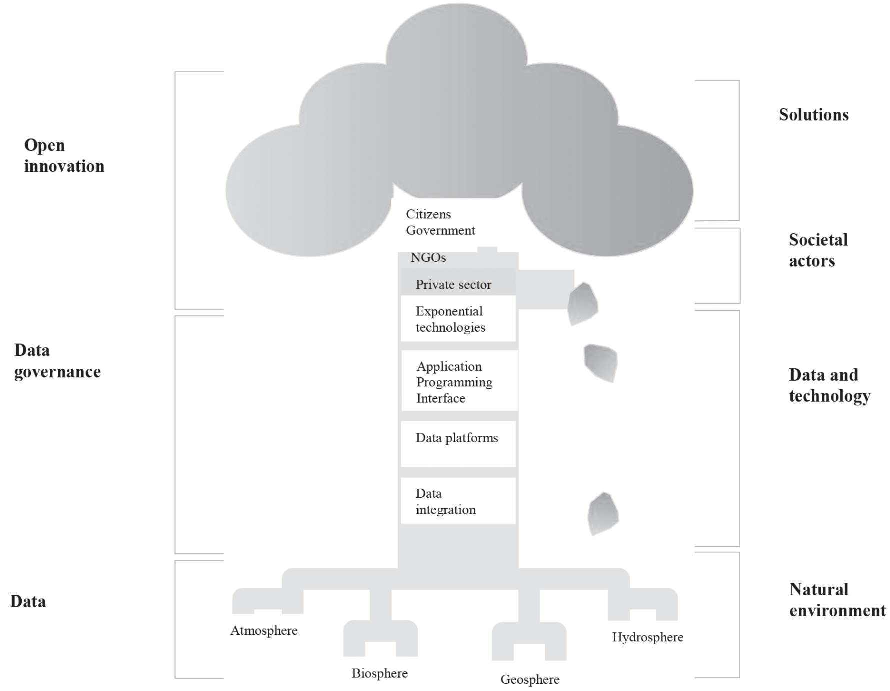
As if the challenge of context with data we have were not enough, there is the problem of substantial data we are missing. Without filling existing data gaps, it is more difficult to monitor progress on environmental objectives and incorporate environmental insight into economic decisionmaking and day-to-day operations.

For example, it is estimated that we are currently missing 68% of the data required to measure the progress made toward meeting the United Nations' Sustainable Development Goals.[6] The investments in sustainability data need to be made at all scales: global, national, state/provincial, city/community, household/family, and corporate/industry.

---

5. Rensselaer Polytechnic Institute Jefferson Project at Lake George, *Home Page*, https://jeffersonproject.rpi.edu (last visited Apr. 7, 2021).
6. Jensen & Campbell, *supra* note 2. *See also* John C. Dernbach & Scott E. Schang, *Making America a Better Place for All: Sustainable Development Recommendations for the Biden Administration*, 51 ELR 10310 (Apr. 2021).

Figure 1. Environmental Data: The Right Data, Governance, and Innovation Grow a More Sustainable Future



Source: IBM Institute for Business Value.

Finally, there is the critical issue of privacy and security. Data about the physical environments in which we meet, work, and conduct our daily activities—especially when combined with health data—raise serious privacy and security concerns. We need a better understanding of how to set the boundaries for data collection and whether there are certain types or sources of data that should be off limits. Also, if we are to link environmental impact more closely to our economic and social activity, we will need to make sure that the data collected is securely retrieved and stored. We will also need to be alert to the potential for data manipulation, fabrication, and misuse—and take steps to prevent it.

All of which point to the importance of data governance.

III. Better Data Governance Leads to Better Environmental Governance

Without the right organization and oversight, big data can end up being a big mess. The right information architecture and governance, on the other hand, can help deliver on its promise. It will enable the integration, interoperability, accessibility, and sharing of data—and allay legitimate concerns about security and privacy.

Ultimately, environmental data governance should accelerate the creation of data-driven collaborative solutions and innovations for environmental sustainability, in part by enabling all relevant stakeholders to participate in creating solutions to environmental challenges. Moreover, appropriate data governance will help align data collection and availability with the environmental objectives, including the need for scientific quality.

Such efforts cannot be confined within national borders—"the environment" does not respect them. Many environmental challenges are international in scope, so it is critical that countries share relevant data and insight. In view of the existential threat posed by key environmental challenges such as climate change, this sharing is an urgent matter and should be viewed as a matter of national security.

In fact, the standards and approach to how nations collaborate and share intelligence for matters of national security may be instructive for environmental challenges. Clear procedures, access rights, and rules for sharing are set for effective and reliable sharing of security intelligence. Similar measures can underpin international data governance for environmental sustainability.

Some regions have already undertaken efforts to share environmental data across borders. For example, the Eionet initiative—European Environment Information and Observation Network—helps share environmental data and knowledge across 38 countries in Europe via a shared platform and common data standards.[7] The initiative also provides best practice and experience in areas such as data management, environmental assessments, and development of appropriate indicators.

7. Eionet Portal, *European Environment Information and Observation Network*, https://www.eionet.europa.eu (last visited Apr. 7, 2021).

While its current focus is understanding the state of the environment across Europe to inform policy, it should be possible to extend the sharing of environmental big data across borders to support the development of innovative solutions and transform business processes.[8] In fact, such efforts have already started within discrete domains. For example, Global Forest Watch is an open-source web application that allows anyone to monitor global forests in near-real time using data from satellites and artificial intelligence (AI).[9]

Environmental challenges also cut across the different ways societies organize themselves. In a business context, the challenges cross industry sectors, demanding cross-sector collaboration. The environment does not care about distinctions such as communications, chemicals, energy, auto, electronics, pharmaceuticals, consumer, retail, travel and transport, and the like.

Take plastic waste, for example. A chemical company cracks ethane that a manufacturer uses to make a plastic bottle. A consumer products company takes the bottle and fills it with a beverage that is sold to a consumer. If all goes well, the consumer places the emptied plastic bottle in a recycling bin, from which a transporter collects it and moves it to a waste management company. There, it is sorted and sent to a recycling company, which transforms it into recycled polyester. A clothing company spins the polyester into a fleece jacket for sale at a sporting goods store. Addressing plastic waste demands cross-industry collaboration, and it can be greatly facilitated by open data on open platforms.

However, the transformation of data into action is often best done locally. Stakeholders are most easily engaged within our communities, cities, and regions, and initiatives are more likely to gain traction at a local level. This calls for a geographically balanced data governance that allows relevant data and insight to be shared at the appropriate geographic level and shared across the emerging distributed generation and accountability system (see Box 3).

Given the wide variety of sources of environmental data—from sensors and satellite imaging to photos and reports from citizens and local communities—it will be important to have processes and standards in place for integrating and verifying the data's authenticity. Its provenance must also be considered before use in subsequent data analysis.

AI and analytics can help with data accuracy and veracity issues. If, for example, data are sufficiently massive, and if a dominant narrative emerges from such voluminous data, quality control for individual data points may become less important, as may the need for precise translation across data strands. AI can play an important role in teasing out these dominant data narratives that have force because of significant data agreement and alignment.

8. Eionet Portal, *About Eionet*, https://www.eionet.europa.eu/about/about-eionet (last visited Apr. 7, 2021).
9. Global Forest Watch, *Home Page*, https://www.globalforestwatch.org (last visited Apr. 7, 2021).

Box 3. Envirosuite: Building a Bridge to Communities With Data*

Regulatory policy aimed at reducing pollution and advancing sustainability has its limits. Compliance can foster a "meets minimum" mindset, both for companies who must comply and in the public's perception of their efforts. A new data-based approach may help shift mindset and perception to greatly improve the relationship between industry and local communities.

Envirosuite, for example, uses monitoring systems, analytics, and the data and insight they generate to help companies pinpoint potential problems as or before they arise. It helps airports, wastewater plants, landfills, construction sites, mining operations, and cities monitor noise, water and air quality, odor, dust, and vibration.

The really interesting innovation arising from this use of environmental data is the willingness of some of Envirosuite's clients to make the data accessible to the surrounding community. This enables the community to see in real time what is really happening.

Consider the challenges created as residential and commercial developments have brought communities closer to airport operations than ever before. Making airport data available to these communities can help build trust and tolerance. A portal to access airport flight tracker data can enable self-investigation to understand the potential source of noise and other issues before lodging complaints.

Building a data bridge between the facility and the surrounding community is, in a sense, a new governance model that is less dependent on government presence and intervention. The primary relationship is no longer between government and the regulated entity, but rather between the entity and the community. This should engender greater public confidence and give the public a key role in the accountability and response mechanism, enabling industries to grow and co-exist with communities in a more sustainable relationship.

* Envirosuite, *Stakeholder Management*, https://envirosuite.com/solutions/stakeholder-management (last visited Apr. 7, 2021).

Turning data from disparate sources into analytical outcomes also requires interoperability and ease of moving data between organizations and systems, which in turn calls for open standards. In that context, cloud computing can help. It can provide the technology infrastructure to mitigate problems associated with having environmental data stored and modeled in many different ways. More specifically, a hybrid-cloud architecture based upon open-source software will ease the transfer of data and work loads across actors and organizations while making data accessible to many.

With greater access to environmental data, individuals and organizations will find it easier to use. This democratizing of environmental data will make it possible to engage a more diverse range of talented people and organizations in open innovation. It will serve as both a motivator and enabler for change. Individuals will be able to take ownership, not only of environmental data, but also of being part of the solution to environmental challenges.

Indeed, if done appropriately, data governance can underpin a new environmental governance that harnesses the full potential of the data and the capabilities of all relevant stakeholders, including governments, citizens, consumers, value chain managers, investors, and financial risk managers (see Box 4). On the whole, the more transparent and accessible the data and data analytics, the greater their power in inducing needed change.

Box 4. Perspective: Citizen Science for Environmental Sustainability

Citizen science offers exciting new opportunities for gathering environmental data and engaging citizens in identifying and developing innovative ways to meet environmental challenges. With a suite of innovative tools and approaches that enable the public to apply its curiosity and talents to environmental science and solutions, citizen science can provide data and insights that would otherwise not be available. Citizen science is already harnessing the energy and capabilities of literally thousands of people to gather data, helping cities and regions understand challenges around air quality, and supporting efforts to improve water quality and preserve biodiversity.

For example, in the Belgian region of Flanders, the *CurieuzeNeuzen* (curious noses) project engaged 20,000 citizens in the monitoring of air quality, providing unprecedented insight into the region's air quality. Similarly, the Virginia Department of Environmental Quality engaged citizens in water monitoring and earned a return on investment of more than 275%.*

Crowdsourcing data from citizens can help fill critical data gaps using untapped resources, while helping to engage communities for action and problem solving. This is particularly the case when citizens are not only seen as sources of data, but are also given access to the data and insights obtained—in effect, engaged as active stakeholders in developing new solutions.

However, citizen science has its own challenges. Most notably, data quality, veracity, and integration can be a concern. When obtained through a multitude of organizations and individuals, the data's provenance and reliability can be difficult to verify. To the extent that citizen science will be a major contributor to enriching our data and insight into environmental challenges, it will be necessary to have strong data governance. As citizen science proliferates and data generation from this stakeholder community increases, data volume may help offset concerns about the quality of individual data points by helping to differentiate between dominant and outlier data strands.

* U.S. EPA, *Basic Information About Citizen Science*, https://www.epa.gov/citizen-science/basic-information-about-citizen-science-0 (last updated Apr. 30, 2019).

IV. Innovation, Open Innovation, and the Environment

Appropriate data governance for the environment provides the foundation for translating data into insight and actions that drive transformation. However, achieving transformation toward environmental sustainability will not happen by itself.

It will require innovation—innovation in core technologies, such as renewable power generation (wind turbines and solar arrays), and supporting technologies (smart grids, smart homes, smart appliances). It will also require new approaches to government policies and incentives, finance, public engagement, and partnerships.

An ecosystem of actors and institutions must drive the required change and coordinate a data architecture for environmental sustainability. Moreover, there needs to be an incentive for them to cooperate, innovate, and share data.

Environmental innovation can come from anywhere. Not just from any actor, but any organization—public or private—from any part of the environmental ecosystem, or beyond.

This requires open innovation: a way to channel innovative ideas from a wide range of different internal and external stakeholders.

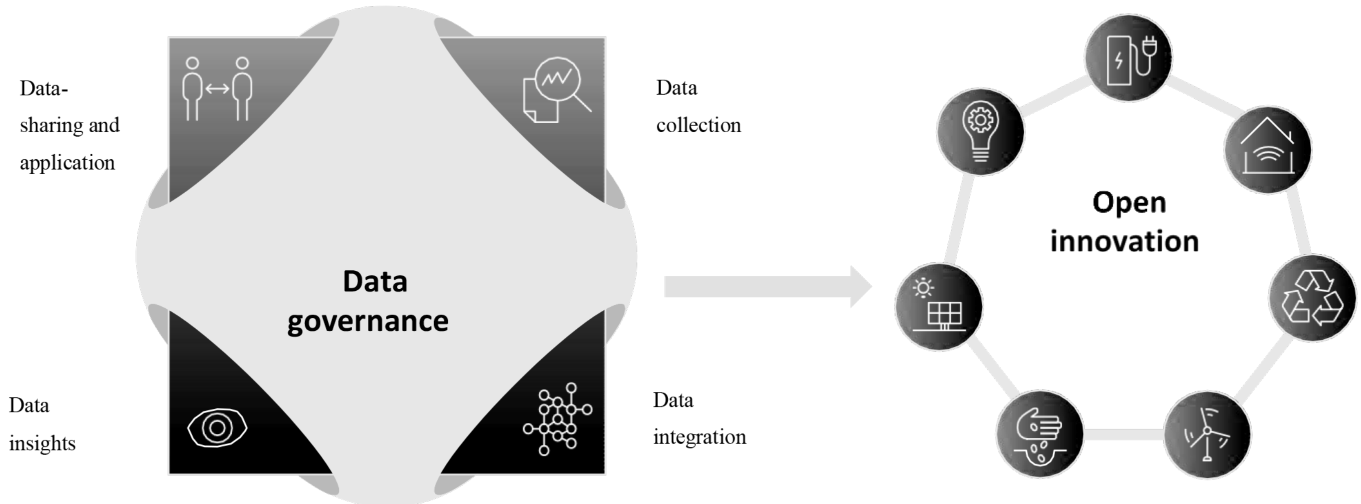
Open innovation goes beyond traditional collaboration and requires organizations to break down silos internally and externally in order to harness the innovative potential of their entire ecosystem. For communities and societies, open innovation means that governments and environmental authorities recognize, enable, and encourage environmental innovation from all groups and stakeholders. They seek to harness the collective intelligence of communities for environmental sustainability. Data—co-created and shared—underpins open innovation (see Figure 2 next page).

To encourage collaboration and data-sharing, organizations must see value in it. Sharing data must create greater value for participants than is possible by working in isolation. Focusing the collaboration on a common pressing problem can help. So can starting small while capturing measurable positive impacts. Then, participants can build on this foundation.

Take the Open Data Cube (ODC) initiative. Recognizing that much earth observation data from satellites is underused, the ODC provides the tools and forum for actors to tap into its potential for new innovative solutions. An open-source ODC community actively engages and contributes to core code, sharing algorithms and providing support to each other to solve problems. Based on the initial success in Australia, it is now being developed at different levels of maturity in 50 more countries.[10]

10. ODC, *About Us*, https://www.opendatacube.org/about (last visited Apr. 7, 2021).

Figure 2. A Shared Future: Data Governance Drives Open Innovation



V. Action Guide for Digital Technology and Environmental Data

To make the best use of environmental data, try a three-fold approach.

First, start by focusing on concrete initiatives that can generate measurable results and show value. Demonstrate the value of data for the environment to obtain more buy-in, create momentum, then scale the initiative. Tangible outcomes—more than just raising awareness—create demand, business cases, investments, and public support.

Second, reinvigorate environmental protection efforts with data. Make environmental data and its governance the central pillars of future efforts by government agencies to support environmental sustainability—becoming more data-driven, fact-based, and empirical rather than anecdotal. Transparency and authenticity will compel action.

This involves retooling traditional command-and-control regulatory approaches to use data for better and more effective interventions. These include allowing for new and data-calibrated flexibilities, such as moving from point-by-point to more ambient-based monitoring and control systems and facilitating greater use of pricing mechanisms and precision regulation. More importantly, environmental protection agencies have a key role to play as convenors and integrators of data for action. As such, they are the curators of the data governance principles for environmental sustainability that ensure that environmental data can be harnessed by all relevant stakeholders.

Third, create new ways to encourage open innovation and collaboration. Include different approaches for the public, private, academic, and not-for-profit sectors to work together to accelerate innovation. Recent experience developing vaccinations against COVID-19 may be illustrative of what is possible.

In response to the pandemic crisis and urgent need, governments, academia, and the private sector have been able to devise funding, procurement, and risk-sharing models—coupled with sharing critical information, data, and research capabilities—that significantly shortened vaccine development from a typical eight- to 10-year process to less than one year. The collaborative efforts also enabled production capacity for the vaccines to scale at an unprecedented rate.

While the pandemic's circumstances may be unique, much of what we have learned can be applied elsewhere: new ways of working, for instance, that have been developed—notably approaches to funding and scaling critical innovation and sharing data—to the pressing issue of environmental sustainability.

Implications for public-sector actors:

1. Foster open data and open innovation as a basis for advancing the environmental sustainability agenda. This requires more than buzzwords. It represents a fundamental shift in how to advance the environmental agenda scientifically, commercially, and through public policy. Open innovation substantially alters the way governments and public-sector organizations engage with each other and other stakeholders. Solutions can come from anywhere. If our environmental governance does not recognize this, we will miss out on the potential for transforming our economies and societies toward sustainability.

2. Establish international agreements on data-sharing and governance to allow innovation and collaboration within domestic boundaries, such as states and regions, as well as across international borders. Environmental problems tend to organize around airsheds, watersheds, and other ecosystems, which are indifferent to political borders. Our efforts to overcome them should likewise be transcendent. Environmental data governance should be a central part of domestic and international environmental agreements.

3. Develop key data governance principles, including access rights, data ownership and accountability, and data quality. Apply these principles to encourage the application of digital technologies as part of precompetitive collaboration. Develop standards and best practices to counter disinformation and poor data quality.

4. Take advantage of latest technology developments, such as hybrid-cloud computing, to provide the technology platform for open data and open innovation instead of captive data and innovation that is restricted to those who agree to play on one provider's closed cloud platform.

5. Seek new and novel data science techniques and combinations of techniques that can address the complexity, variety, and veracity challenges of environmental data. To this end, enlist AI and machine learning.

6. Build core competencies for data collection, analysis, and management to support regulatory policy and collaborative frameworks that utilize digital technologies.

7. Lead by example and actively use public procurement and various funding models to drive innovation for environmental sustainability with private-sector partners.

8. Cultivate government leadership capable of catalyzing supporting architecture, helping build a bridge between data generation/analysis competitors, shaping data governance systems, and adapting environmental regulation to the digital age.

Implications for private-sector companies:

1. Integrate environmental sustainability firmly within your corporate strategy. Ascertain the opportunities and challenges posed by environmental sustainability for different parts of your business.

2. Assess how data and digital technologies can improve your operations and enterprise workflows while achieving better environmental outcomes. For example, as production processes and supply chains are optimized with data and digital technologies such as AI, find opportunities for reducing your organization's environmental footprint.

3. Work with ecosystem partners from within and outside your industry to accelerate improvements to your workflows and the development of new and more environmentally sustainable products and services. Actively expand your ecosystem as needed to include partners from the private, public, and not-for-profit sectors.

4. Transform your operating model for open innovation. Put in place the right capabilities, technologies, and processes to innovate openly for the success of your business and better environmental outcomes. Break down internal and external barriers to cooperation where needed.

5. Integrate your digital transformation and environmental sustainability strategies. In so doing, apply open standards to your technology architecture and platforms to allow for interoperability and sharing data with ecosystem partners.