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Disruption. This one word captures the essence of the world today. COVID-19 has disrupted economies, global supply chains, health systems, travel, education, and so much more. In just a few weeks it changed life as we knew it. But COVID-19 is not a “black swan”; it was not unforeseen and unexpected. A global pandemic is just one of many global systemic crises that scientists have long predicted would emerge from our disruptions of Earth’s life support systems (1)–(3). Over the last several decades, human disruptions to the climate, the ocean, and all natural ecosystems, have expanded and intensified the risks to human health, security, and prosperity (4). COVID-19 provides a window into how prepared the international community is to handle the larger crises on the horizon resulting from disruptions to the climate and other Earth systems.

Disruptions can have positive as well as negative impacts on natural and human systems. Among the most fundamental disruptions to global society over the last century is the rise of big data, artificial intelligence (AI), and other digital technologies. These digital technologies have created new opportunities to understand and manage global systemic risks, and drive the societal transformations needed to overcome them. COVID-19 has highlighted how critical digital technologies are

to managing global systemic crises. It has also put a spotlight on the profound challenges that parallel the transformative opportunities of building a sustainable and equitable world in the digital age. In the context of the pandemic, big data and artificial intelligence are helping society track and manage the spread of the disease (5)–(7). In the case of climate change, similar tools are being explored to track carbon, analyze climate risks, and reimagine climate governance (8), (9). The digital sector is also helping to mitigate the cascading impacts of emerging crises. Imagine if COVID-19 happened 20 years ago, before Google, Amazon, Facebook, or Zoom enabled so many people to stay connected to each other and the world. Without these tools the impacts of “shelter in place” orders and global economic shutdown would have been much starker for many. But not everyone is benefiting from these tools. Almost half the global population does not have access to the digital world (10), and even among those who are online, many are unable to do their work remotely. Furthermore, while the digital sector is a lifesaver to many, it can also facilitate the propagation of disinformation, under-

mine trust, and ultimately threaten democracy (11), (12).

In this special issue, we explore the opportunities and challenges of leveraging AI and other digital capabilities to drive the transformative system changes needed to tackle the climate crisis and related global sustainability challenges. The work presented here was initiated well before the pandemic emerged, but the current crisis makes the issues explored in these papers even more poignant for challenges we face in building the world we want. This Special Issue is an outgrowth of Future Earth’s Sustainability in the Digital Age (SDA) initiative and an international workshop held in Montreal in September 2019. The workshop was one of a series on AI and Society, hosted by CIFAR and supported in partnership with U.K. Research and Innovation (UKRI) and France’s Centre National de la Recherche Scientifique (CNRS), and organized by Future Earth, the U.K. Office for AI, the International Observatory on the Societal Impacts of Artificial Intelligence and Digital Technologies (OBVIA), and CNRS. This three-day workshop brought together 28 experts from academia, industry, government, and civil society to explore

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the intersection of technology, sustainability, and policy. The ideas and discussions that emerged throughout the workshop were captured by the facilitators through graphics that are featured throughout this special issue.

In this publication, we highlight perspectives from workshop participants who are engaged, from different vantage points, at the intersection of the sustainability and digital sectors. We include articles from researchers working on both the mechanics and ethics of AI and machine learning, analysts working on data and digital governance, scientists studying environmental and human dimensions of global environmental change, and leaders from both the sustainability and digital policy worlds.

The first two articles are products of a year-long international collaboration of over 250 subject matter experts on how to leverage the digital age to drive the transformative systems changes needed to build a climate-safe and equitable world. The first article, “The Montreal Statement on Sustainability in the Digital Age,” is a direct product of the September 2019 CIFAR workshop. It is a collective statement of the workshop participants highlighting the urgency of the climate crisis, the transformative power of AI and other digital capabilities, and the profound risks and opportunities of leveraging these digital capabilities to tackle climate change. The Montreal Statement outlines near-term actions needed to overcome these risks and leverage the transformative power of digital capabilities to build a climate safe and equitable world.

In the second article, Luers *et al.* provide an overview of the “Digital Disruptions for Sustainability Agenda” (the D²S Agenda) (13), released in March 2020, which identifies priority research, innovations, and actions for driving transformative change on climate. This article explores the

drivers of systems changes, rooting its analysis in Donella Meadows’ framework of leverage points for systems change. Luers *et al.* identify potential digitally-empowered levers for change within the dominant economic, governance, and cognitive systems. These initial two articles are followed by a collection of commentaries, opinion pieces, and analyses that elaborate on some of the ideas in these initial two papers.

Havens offers a perspective on the role of AI technologies, the concept of exponential growth and environmental “techno solutionism” in determining metrics of success for humanity. He points out the danger of applying these technologies to address specific areas of environmental decline at the expense of systems thinking. He urges us to consider new metrics of success that account for systems thinking, and that include fundamental components of today’s societal infrastructure, namely those of caregiving and environmental health.

Messner discusses how AI technologies challenge humanism and true democracy, and proposes the need for Renewed Humanism resulting from the opportunities of the digital age. He explores four perspectives to consider in the establishment of Renewed Humanism. Within these perspectives, Messner discusses the humanistic principles emerging from the Enlightenment that need to be preserved, the blind spots therein that can be built upon, the implications of the evolving nature of humans and machines as they become increasingly intertwined, and how to mobilize the potentials of the digital age for a civilizational shift towards Renewed Humanism.

Khareghani discusses the role of AI technologies in U.K. policy and economy. She highlights the work being done by the U.K. government at the intersection of AI, decarbonization efforts, and climate change and dis-

cusses the challenges ahead. She provides an overview of the implications of decoupling carbon emission with economic growth, and offers a practical perspective on the transformational potential of AI for the energy sector.

Luccioni *et al.* discuss the importance of tracking and communicating the environmental impact of AI technologies. They provide an overview of the factors involved in estimating machine learning (ML) carbon emissions and present a tool for tracking ML emissions (<https://mlco2.github.io/impact/>). They propose concrete actions that can be taken to reduce the ML carbon footprint and call for increased consideration of the carbon emissions of AI technologies.

Pitt *et al.* highlight the importance of reflexivity in the ability of dominant social, economic, and political institutions to adapt as they evolve. They outline four dimensions of reflexivity, each of which poses tensions between two drivers specific to that dimension, and where the tensions in each dimension generally rely on deliberative processes for an outcome. They propose an algorithmic approach to the deliberative and meta-deliberative processes required for institutional reflexivity. More specifically, they provide a framework for algorithmic reflexive governance of interdisciplinary socio-techno-ecological systems, blending ideas from AI and Democratic Theory at the intersection of these systems.

Lahsen points out that while mainstream academia highlights the importance of public mobilization for transformative policies, it fails to acknowledge that transformative change requires interventions in the political economy of traditional and new, AI-infused media. These media and technologies are inherently infused with values and used to serve political goals. Recognition of this should spur action to ensure that they are democratically governed

and serve the common good — because steer us they will, regardless. We should be asking how mass media and the algorithmic power of artificial intelligence can be used in an ethical and democratic manner to help foster the vitally needed changes in institutions, values, and worldviews to achieve the sustainable development goals without transgressing planetary boundaries.

Girard calls for international data standards, as the volume of data flows exponentially increases and the cost of data collection and storage decreases. He draws our attention to the issues that can arise from a lack of data governance, especially given the absence of a UN-mandated international framework for digital cooperation. He suggests that, while the adoption of the United Nations' Sustainable Development Goals offers many opportunities for digital cooperation, standards for interoperability are needed to facilitate the data pooling and sharing required to successfully address these goals. To this effect, he proposes a concrete framework for a Data Standards Task Force, which would create the architecture for a "single data zone" governed by an "International Data Standards Board".

We are thankful to all of the contributors to this special issue, both article authors and to those who contributed ideas and perspectives through online dialogues and in-person workshops over the last year. The articles in this issue highlight the magnitude of the opportunities and risks of leveraging the digital age to drive the transformative systems changes needed to build a climate safe and equitable world. They outline critical normative and ethical questions, point to technical constraints to progress, explore the potential for transformative changes, and illustrate practical approaches for moving forward. The COVID-19 crisis demonstrates how human-

ity today is interconnected through and increasingly dependent on both the natural and digital worlds. With these interconnections comes unimaginable powers that need to be explored, stark inequities that need to be addressed, and profound ethical issues that need to be considered. We hope these papers help researchers, innovators, and policy makers navigate the path ahead.

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