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AI for sustainability: A changing landscape

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Artificial intelligence (AI) is impacting society in varied ways as researchers and practitioners are using it to gain new insights into different problems and to open up new business opportunities. Its use has expanded from industry and manufacturing, to areas of sustainability such as land, water, biodiversity, urban transportation, waste, energy supply and housing. AI has revolutionised and will continue to shape the way experts find solutions to problems in these areas. At the core of this transformation are two inseparable partners: “data” and “machine learning”. A huge amount of data is generated by people and all forms of sensors.[1] Never before has our world been so extensively documented. Some suggest that around 90% of all the existing data in the world has been created in the past few years.[2] This data is then used to create advanced machine learning models that can then be used to transform data into assessments, predictions and decisions for action.

We are talking about shifts in technology and society along spectrums of interactions and new possibilities, not some sudden revolution that will happen in the future. It is already with us; it already shapes our behaviour. Near real-time wind, rain and temperature maps are readily available to us on our mobile phones already. We know a lot about our surroundings, but also — simultaneously — we have access to knowledge about places thousands of miles away from us that we have never visited in person. With a few key phrases, we can quickly come to understand the past, present and sometimes future of these places. We live in a world where sensors track many movements, small or large: from ships in the oceans to sheep in the grasslands. Whether we like it or not, today we trust Google Maps and GPS positioning applications more than we trust each other's sense of direction. Our mobile phones help us to navigate through unfamiliar streets and traffic conditions, or tell us how long before an Uber driver arrives. Many sensors in shopping malls and online companies watch our every move, including purchase transactions. Every post on social media provides yet more rich data on people's interests, values and often location.

This data is the fuel that powers machine learning — the most prevalent form of AI in use today — and shapes how it operates. All advanced machine learning algorithms that enable the computing aspect of AI rely heavily on the data collected from sensors to assess the "past" and predict the "future" in order to make strategic decisions in the "present". These systems are so embedded in our daily routines and central to our experience of culture and life that we use them without thinking about them, or recognise them as computing per se. For instance, we use them when we accept words and phrases suggested by our email, or when they help us decide whether to leave town before the cyclone comes and tells us where we can go to be safe. The line between being a human and something often called "cyber", is becoming blurred: humans are becoming moving cyber-physical systems.

Living through this technological revolution has made many come to the conclusion that our modern society is at the dawn of the next industrial revolution: a transformative change that is yet to be fully realised.[3] All previous industrial revolutions have brought countless advantages to the world: mechanical production and steam power energy, electrical energy, mass production and internet technologies. They all brought significant economic growth, better health and more efficient ways of working to the world's population. Furthermore, they brought us changes in culture by further connecting societies with new means of trade, transportation and communication.

These revolutions, however, have brought problems of their own, as they caused unsustainable interactions between modern social systems and nature. The result has been catastrophic for the Earth's ecosystems and all their life-supporting services. Natural resources have been depleted, biodiversity lost, wildlife threatened, forests cut down, rivers polluted and extreme weather conditions have become more frequent. As a result, geologists have concluded that the Holocene has ended and a new epoch has begun. They believe that humans' intervention in the Earth's ecology is so substantial that humans should be classified as a geological factor. Although this new epoch, which is called Anthropocene, has no agreed start-date, atmospheric evidence suggests it started with the first industrial revolution and the invention of the steam engine.[4]

From the consequences of unsustainable interactions with nature, it has become clear that it will be difficult for the Earth to continue to exist in its current ecological state if human civilisation does not balance the negative impacts of industrialisation with its positive impacts. If we are indeed at the dawn of a new industrial revolution, our future on this planet looks unsustainable if we simply build on the practices of past industrial revolutions.

Sustainability scientists and practitioners can play a significant role in the future direction of the planet. They can ask questions, frame problems and find solutions that enable regulators and policymakers to address the most pressing socio-environmental challenges of our time: climate change, air pollution, water and land use. They must find ways in which societies can live in harmony with the planet and at the same time accommodate peoples' growing needs and aspirations. This is not an easy task by any means, particularly considering the rapid pace of technological change and development.

The unprecedented development of AI poses some new questions to sustainability experts: "What is the role of AI in the future of sustainability domain?", "Can we call AI a 'game changer' for sustainability or is it just old algorithms which have been re-branded?", "If it is a real game changer, what is its key potential to accelerate sustainability efforts?"; and, more importantly, "What are the major challenges?"

This chapter aims to unpack AI as it is used in the current landscape of sustainability conversations and discusses the challenges and opportunities arising from it in the 21st century. We will now introduce the three arguments currently used to advocate for AI for sustainability. Although the proposed categories are highly interrelated, this chapter will deal with each separately.

The emerging place of AI in the sustainability conversation

It is easy to fall into the trap of making general arguments about sustainability and sustainability expertise, but there are many ways a sustainability expert can interpret social and environmental challenges and provide solutions for them. For example, radical green experts, having roots in the philosophy of “deep ecology”, strongly believe that society and the economy should be subservient to nature (and disappear if need be), whereas more pragmatic experts work closely with corporations to balance their environmental and social responsibilities with their business efficiency and productivity.

Living at the intersection of the fast-growing world of AI and the Anthropocene age, many of these sustainability experts have become interested in bringing the world of AI and the Anthropocene together, each for their own valid reasons. They use data science and machine learning for their projects and activities. Here are some of the major areas where AI could aid sustainability experts:

- Supporting better environmental management (e.g. water, pollution) with data collected by autonomous systems operating in the maritime environment, on the ground, in the air, and in space;
- Predicting climate variability and changes, so as to better recognise the likelihood of extreme events through improving existing climate models (e.g. drought, floods, hurricanes) using satellites and ground sensors;
- Enhancing local biodiversity and crime prevention (e.g. anti-land-clearing, anti-poaching, pollution monitoring

and conservation law) using motion-sensor cameras, audio signals, drones, and GPS locators; and

- Improving the sustainability of agricultural management practices using robotics, wireless sensors, and remote monitoring devices.

This wide range of applications of AI strongly suggests that it is an important part of the future of sustainability. While not everyone agrees with this premise, governments, international organisations, NGOs and private corporations have already begun to invest in AI. "AI for sustainability" is currently the topic of many conferences and workshops around the world.

AI for monitoring sustainability

It is an exciting time for experts working in environmental policy, environmental monitoring and compliance as new technologies have opened up so many opportunities for disruption. With a few cameras, microphones, and thermal and chemical sensors, scientists can monitor sustainability issues quite inexpensively. The sensors provide constant, real-time data that can be used to understand the health of forests and animals, river basins, and coral reefs. Sustainability professionals can be more creative by diversifying their data acquisition methods and experimenting with the ways they connect societies to nature. For example, the City of Melbourne recently experimented with a new platform which allows citizens to contact a tree and ask it how it is going.[5] The platform sends back an instant response based on data coming from sensors, which might be "hey, I'm doing great ☺" or "I'm stressed today. Guess I'm dehydrated ☹". Add to this new avenues of data collection such as satellites, remote imaging and autonomous monitoring vehicles, all of which generate datasets larger than any encountered in the history of sustainability science. Yet, to be useful in creating opportunities, these datasets still need to be transferred to data centres for sharing, processing and long-term storage.

It is in the acquisition, preparation and interpretation of the data that machine learning algorithms present themselves as game-changers. They make it possible for those with expertise in handling data to generate (useful) predictive models of highly complex systems without achieving the incremental understanding that more traditional efforts would typically require. Furthermore, they can be used and integrated into other higher level services in all areas of life and work. The transition to this new form of augmented analytics has the potential to make monitoring processes much faster, more accurate and smarter. Smarter because they sometimes find unanticipated trends and patterns that would otherwise escape the expert eye.

The astonishing progress in AI is going to be critical for monitoring sustainability in years to come. Deep learning, as a class of machine learning, has already attracted considerable attention from researchers of all over the world. It empowers experts to go one step further and find patterns that are hard for rule-based systems to adequately capture. This is yet another jump in efficiency that has transformed the AI industry, resulting in models with the capacity to carry out natural language processing, speech recognition, image recognition and so forth with unprecedented accuracy.

By combining deep learning algorithms and satellite images, new opportunities have been opened up for regulators and policymakers to monitor the social and environmental conditions of systems they are responsible for. Examples are many and varied, ranging from using them to identify regions of poverty in Africa, to detecting violations of the Clean Water Act in the United States.[6] However, government bodies are not the sole actors in this landscape; computer corporations have also made strides to invest in this area. Microsoft's $50 million investment in its 'AI for Earth' project, for example, is designed to support the use of AI among sustainability experts. The initiative gives institutions around the world access to Microsoft's cloud and AI computing resources. A part of this investment is to provide training so sustainability experts can learn more about the potential of AI tools for their projects. Table 1 includes two examples of sustainability challenges and AI solutions, supported by Microsoft's AI for Earth initiative.[7]

Examples like this clearly support the idea that sustainability experts are, and will be, in a good position to aid decision making using AI systems — collections of sensors and AI models — to collect data about the current state of forests, rivers, and reefs, and extract trends and patterns from them regarding deforestation, desertification, and bleaching.

However, despite all this potential, there are flaws and challenges. First, similar to all other AI applications, adoption of AI for sustainability poses ethical, social, and regulatory challenges to researchers, companies, and policymakers. Machine learning algorithms used for sustainability purposes can perpetuate bias or a prior status quo when they use data from the past to predict the likelihood of a sustainability

Table 1. AI as a solution to sustainability challenges (two examples from Microsoft's initiative "AI For Earth")

The challenge	The solution
Climate change and human activity are altering the natural landscape. In order to conserve these landscapes and build climate-resilient communities, conservationists need accurate data on the changing environment.	Using algorithms on the AI platform that are integrated into ArcGIS spatial mapping software, we are able to create a fine resolution land map. These algorithms help conservationists track changes in landscape over time.
Citizen scientists make tremendous contributions to biodiversity research by taking and identifying photos of plants and animals. But the identification process remains dependent on human experts, creating a bottleneck in the scientific pipeline.	Using the AI platform, specifically the Deep Learning Machine, we can train a deep neural network to identify plant and animal species in images taken and shared by people participating in the project.

challenge in the future; for example, in using past datasets of run-off and rainfall when there have been step changes due to climate change and landscape alteration.

Second, they can be gamed or tricked into producing a wrong or maliciously desired result — particularly if those who might benefit from it (e.g. poachers, polluting industries) know how the algorithm works.

Third, AI models used for sustainability could work autonomously and interact with one another, creating machine-centred feedback mechanisms; for example, by deployment of AI as energy optimiser in buildings creates new interactions between the building's energy use and the whole system's energy use. Since each building operates individually without considering the whole system, regional energy systems could easily fail to supply required energy needs.

Fourth, it could potentially exacerbate environmental injustice concerns by directing attention of policymakers to, or away from, specific locations or communities; for example, autonomous emergency food delivery services in a disaster that are trained using historical demand patterns will direct supplies to specific regions when a hurricane hits. This could create ethical challenges relating to prioritising response efforts, and accountability.

Fifth, since data sources are heterogeneous and becoming more and more complex and diverse, managing and utilising them in an integrated manner is becoming increasingly difficult, especially when the data has been collected by different organisations for different purposes on different temporal and spatial scales. In addition, for each dataset, different methods may have been used to achieve a certain resolution.

And sixth, AI for sustainability has a carbon footprint. Machine learning, like other intensive computer processes, uses a large amount of energy, and this poses an overall threat of creating environmental harm towards nature and societies.

AI for computing sustainability

Along with augmenting monitoring, AI has also opened up new opportunities to compute sustainability. Computational sustainability at its core is concerned with developing new models and methods to help adjust the levels of sustainability indicators towards their desired positions. Monitoring and computing are tightly interrelated, and both have the potential to improve our problem framing and solving. Therefore, any improvement in one will result in a multiplying effect on the other.

As monitoring techniques and technologies advance, so too does the ability of machines to better analyse and compute sustainability. New sensor platforms (e.g. deep ocean gliders, drones) collect various genres of data with differing quality and resolution. Through citizen science projects, people become self-guided sensors, helping experts to complement their datasets. Simple initiatives, such as Melbourne's checking-in with trees concept or bird watching, can make a big difference. In the example of bird watching, an expert can apply machine-learning techniques to the observations of birdwatchers and create high resolution maps of birds' habitats in order to determine if a hunter can purchase a permit for game hunting.

Advances in AI have encouraged experts in the field to explore the possibility of a new era of computational sustainability. Cases like these are just examples of a computational sustainability, which begins with data from sensors and ends with a decision.

Although the use of AI in this capacity continues to gain momentum, the basic process of computing sustainability remains the same as previously described. A sustainability expert is still engaging with collecting and consolidating a range of data, finding actionable patterns in them, and testing and acting on those patterns through scenario planning — a process based on a long history of modelling in sustainability science that always begins with data collection and ends with decisions. These efforts are mainly focused on three broad areas:[8] (1) optimisation, (2) prediction and classification, and (3) exploring policy pathways.

There is considerable precedent driving this exploration. AI optimisation techniques in the environmental field, for example, have been around since the 1980s and are used extensively in support of sustainability challenges. Machine learning and data mining have been useful tools in ecological, hydrological, and climate modelling, with their use dramatically increasing since the 1990s. More recently, with support from cloud computing, computational sustainability has gained a new foothold in business and academia. Given this background, computational sustainability has mostly been used in the development of decision-making algorithms that can allocate resources efficiently based on information extracted from image-like data and sequential data.

But challenges to advancing this new computational sustainability remain, as the existing work often uses AI to find a solution to sectoral problems by optimising societal, economic and environmental resources individually. The integration is often missing in action. There are few good examples of computational sustainability built on the logic of sustainability as a whole; for example, "integrated assessment and modelling". However, it is yet fully understood in what way we can develop sustainability models that effectively integrate many of the economic, environmental, and societal aspects of relevance to these systems — one in which all these important aspects of wider systems are implicitly captured by AI models and then used to shape higher level decision-making processes.

AI for reducing unsustainability

The third argument used to advocate AI for sustainability is to reduce unsustainability. Of course, we can take the above-mentioned examples and use them here as AI applications for reducing unsustainability. Many researchers in the field suggest that a direct result of using AI is a significant increase in efficiency. And since efficiency results when waste of resources is reduced, it signals that we have reduced a practice that was unsustainable. For example, the use of sensors and automation at farms improves crop yields and agricultural output. Having access to sensor data allows a farmer to develop a new understanding of the farm's current state. Also, it gives farmers the power to anticipate problems before they arise. They can plan how much grain to buy for their livestock the following year, based on what the algorithm suggests. That means the use of AI creates more environmentally friendly and less wasteful farming practices.

However, this is not necessarily true if we look at it from a broader perspective. While AI might help reduce unsustainability on the farm, optimisation at the farm scale may unintentionally lead to unsustainability at the river basin scale, where cumulative impacts of reduced "losses" of water across a landscape can lead to a lack of flows returning to groundwater systems and environments.[9] Climate is the other classic example used in this area. The main argument is that by using AI, our societies will be better positioned to tackle climate change. Experts believe that AI enables them to monitor and compute CO_2 emissions more accurately and subsequently inform decision makers on what action to take. Additionally, AI could potentially be used to reduce CO_2 emissions by increasing the efficiency of other practices across the whole of society. For example, it could lead to smarter farming practices and less fuel consumption as a result of using autonomous systems in transportation and manufacturing. Those who subscribe to these ideas tend to see AI at scale, when things are connected and all planned efficiencies have been achieved. In fact, the bigger claim here is that AI can help decouple economic growth from CO_2 emissions. A recent report co-produced by Microsoft and PwC supports this claim.[10] According to the report, using AI for environmental applications in just four key industry sectors could reduce CO_2 emissions by 4% worldwide, contribute up to $5.2 trillion dollars to the global economy, and create 38.2 million net new jobs by 2030.

Alternatively, AI in itself has a carbon footprint, as it consumes massive power to compute. New research suggests that the carbon footprint of training a single AI model is equivalent to 284 tonnes of CO_2, or five times the lifetime emissions of one average car.[11] Training a single model is the minimum amount of work an expert does. In practice, the process of building and testing a final model requires training thousands of models — and depending on the circumstance in which it is likely to be used, this “final” model may only be useful for a fixed amount of time. An AI program needs to be trained on a large amount of input data such as images and continuously running computations on them (sometimes running multiple GPUs all day long).

Now add to this the fact that AI is usually embedded in, or comes with, other technologies such as robotics, networks, electric vehicles and more, all of which require significant energy consumption. Although there is no exact estimate, there is research to suggest that data server farms and connected devices could consume one-fifth of global electricity by 2025, while producing 3.5% of global emissions.[12]

Now that we have explored a range of trends in AI for sustainability practice, we now shift to a discussion of what these themes mean for expertise in sustainability more generally.

The current landscape of AI expertise in sustainability

The current landscape of expertise in sustainability is changing as AI becomes ubiquitous and makes its way into mainstream conversations. Experts are increasingly required to not only understand many aspects of the sustainability challenges (e.g. ecological and biological interdependencies, stakeholders' competing interests, opportunity costs, animal behaviour), but also to have experience in computational thinking (e.g. abstraction, optimisation, differential equations).

Expertise and experience in computer science, statistics, mathematics and data science are regarded as enterprise skills and are in high demand. Grant funding to support AI initiatives in the sustainability domain is available from a variety of sources. Experts are increasingly needed to help their hiring institution make the transition to the AI world. Therefore, in order to remain employable into the future, many sustainability experts are developing their programming skills and knowledge of computer languages, such as Python. This has created a surge of interest in machine learning among students.

Students recognise that the skills needed to create transition are highly prized in multiple career pathways and sectors due to the rise of data science — the science of extracting useful insights from data — in almost all professions, ranging from banking, and security, to astronomy and health. In other words, once they know about data science, machine learning algorithms, and models, they will have multiple career choices beyond sustainability. Although this provides students with more flexibility in their career opportunities, it could hinder them as the next generation of sustainability experts from deeply engaging with their profession.

The bigger risk, however, is that these students just learn to program, without fully understanding both the opportunities and risks that AI approaches might introduce into their work. The consequences of this could be far more problematic when these students are hired by institutions who are transitioning towards becoming more reliant on AI-powered technologies to monitor and assess environmental sustainability — for example, an environmental agency transitioning towards replacing its conventional human-based data collection methods with an advanced land or sea-to-space monitoring systems that includes satellites, unmanned airborne systems, and autonomous surface or underwater vehicles.

Most of these institutions are interested in staying ahead of (or at least keeping up with) the curve and wish to remain relevant in light of the technological changes happening in society. Also, as part of their mission, these institutions often play pivotal roles in helping government, industry and the wider community make informed decisions about sustainability issues. There are good intentions here, and true possibilities for improving the status quo, but there are also risks. Therefore, it is important for students and junior professionals in the field not to be distracted by applying AI as an objective unto itself and to consider its wider implications.

Currently, these institutions often partner with companies such as IBM, Microsoft and Google to reduce the mismatch between their capabilities and the skills required to successfully transition to the world that powered by AI. However, as discussed in the previous section, the challenge for these institutions goes beyond developing a broad spectrum of enabling technologies, or building models and decision-support tools. It is more about the wide range of organisational, professional, cultural and regulatory challenges that this shift will present. How will AI change sustainability practices and practitioners, and what do these changes mean for the future of the sustainability science?

Towards training new practitioners

To remain at the forefront of this new technological revolution, it is crucial that we are proactive. We can begin by asking deeper questions that will make designing, planning and management of AI and the systems they are embedded in more effective for addressing sustainability concerns in the long run.

Questions such as:

- What is the purpose of investing in and using AI for sustainability? How does the investment in AI contribute to addressing sustainability challenges in the longterm?
- Will AI technology used for sustainability have autonomy? In other words, to what degree will it be able to make decisions about what and how to monitor/model/influence sustainability in the absence of an expert?
- What safety, ethical, risk and uncertainty issues arise when the environment is populated by all manner of sensors, networks, autonomous vehicles and other infrastructure required to enable AI-at-scale for sustainability?
- What are the metrics for determining the effectiveness of "AI-for-sustainability"? What are the sustainability indicators that tell us when it is time to change or adjust?

- How will sustainability experts interact with these technologies and what will it mean for populations across the world in terms of interacting with these technology-filled environments?

These are difficult, yet important, questions to be engaging with. Unfortunately, the experts who are keen to use AI for sustainability rarely focus on such issues. In addition to technicians and engineers trained to work on cutting edge AI technology, we need people who do not get overwhelmed by the rapid pace of technological change and are comfortable enough to ask difficult questions. They must have the capacity to engage with diverse aspects of potential problems and consider the relevant technical, social, environmental, political and economic factors before proposing a solution or making a decision related to them.

We need experts who can maintain a holistic view while helping people and institutions around them transition to the new world. This includes helping them to undertake a deeper analysis of the possible uncertainties and to work towards minimising social, political and environmental impacts of the technological choices they make. We need practitioners who do not overlook the long-term and secondary impacts of AI solutions, but who can help navigate AI and influence the world in ways that ensure long-term sustainability. It is critical that we move towards training sufficient numbers of these new practitioners. Perhaps this is the real gap that needs to be closed before AI is scaled up.

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Endnotes

1 Much of AI is based upon datasets collected and curated into databases by humans (with all the errors this may involve). The vast quantity of data accessible to humans is facilitated by sensing systems, data capture/cleaning/storage methods and facilities, and the ever-increasing interconnectedness of our digital world.

2 In 2013, IBM reported that 2.5 quintillion bytes — the equivalent of 2.5 million 1 TB hard drives — of data are created every day.

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7 "AI for Earth" is a five-year, US$50 million Microsoft initiative that supports, and partners with, environmental groups and researchers.

8 All efforts in this area begin with a form of "framing" and "goal setting" before optimisation, prediction and classification, or exploring policy options.

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