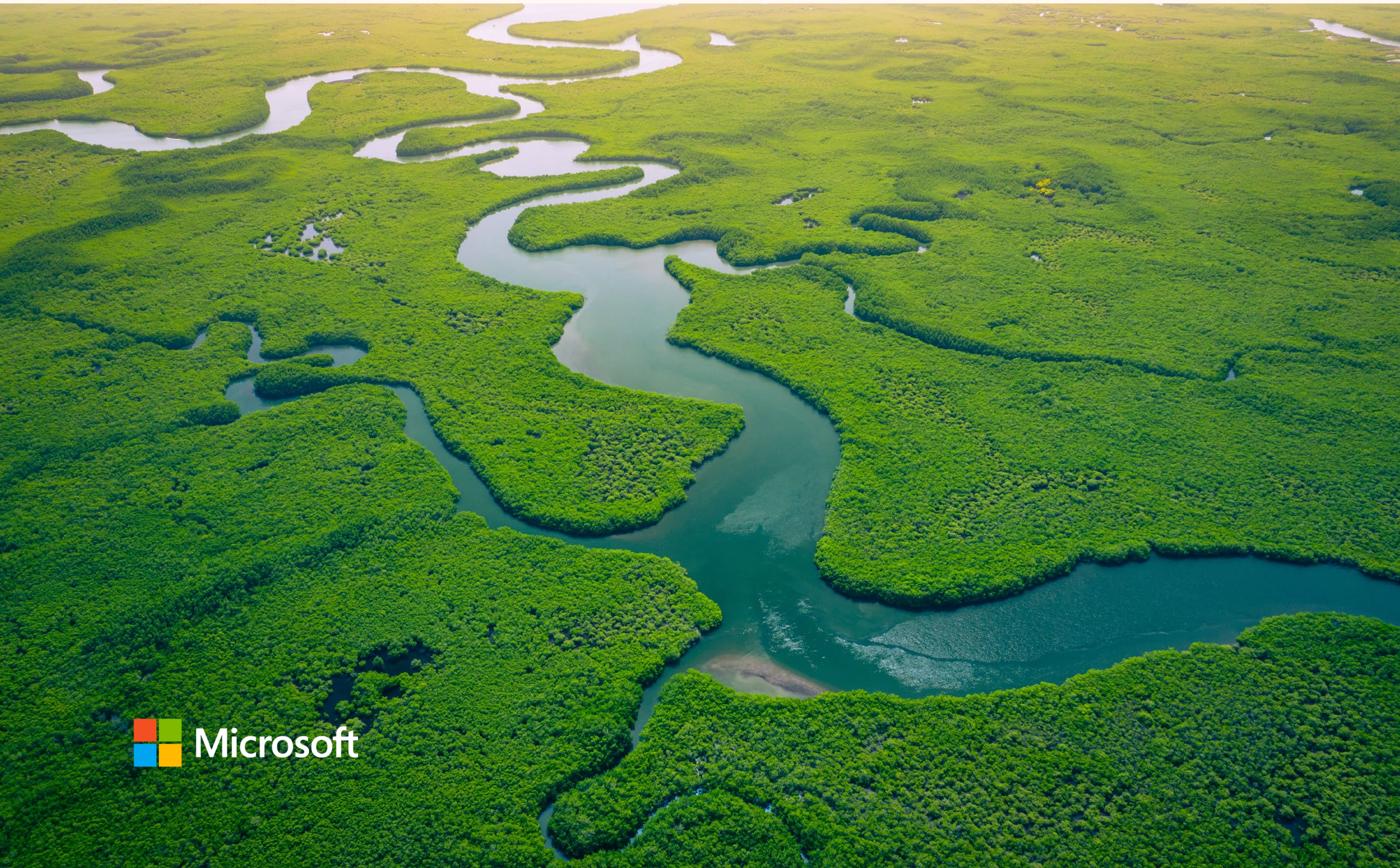
Advance Sustainability

Accelerating Sustainability with AI: A Playbook



Microsoft

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The authors would like to thank the following people for their contributions:
Avi Allison, Rachel Azafrani, Adina Braha-Honciuc, Marybeth Bucklen, Darlene Campos, Ranveer Chandra, Ornella Cosomati, Aaron Cragin, Austin Dowling, Monica Duda, Michele Falcon, Joanne Fischlin, Nate Foote, Kelsey Grey, Janet Guo, Ethan Jackson, Sean James, Daniel Kluttz, Owen Larter, Audrey Lee, Nick Michetti, Brianne Miller, Bichlien Nguyen, Cassie Pemberton, Shane Peterson, Eliza Roberts, Vickie Robinson, Jeremy Rollinson Sarah Scott, Charlie Sellars, Jake Smith, Tjade Stroband, Annika Swenson, Heather Wikene, Mikaela Winter

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Foreword

AI is an essential tool for accelerating sustainability

Given the urgency of the planetary crisis, society needs to push harder on the AI accelerator while establishing guardrails that steer the world safely, securely, and equitably toward net-zero emissions, climate resilience, and a nature-positive future.

This year the world experienced the impacts of climate change like never before, from devastating wildfires to extreme weather. We are seeing and feeling the impact of climate change in our communities every day, and the science is clear: we need to act at an unprecedented scale and pace to address this crisis. It's an enormous challenge and an enormous opportunity for the world to accelerate climate progress.

At Microsoft, we believe that for our company to do well, the world also needs to do well. We are at a critical moment for environmental sustainability, and we need government leaders, businesses, and civil society working in tandem. We also need to use every tool at our disposal to aid us in this journey, including AI.

AI is a vital tool to help accelerate the deployment of existing sustainability solutions and the development of new ones—faster, cheaper, and better.

In this paper, we outline the opportunities that AI provides for accelerating sustainability and the actions needed to ensure that we unlock the full potential of AI for sustainability.

AI's three game-changing abilities

On the journey to net zero, the world has faced many bottlenecks to progress. AI has three unique abilities that can help society overcome key bottlenecks to this progress. These include the ability to:

1) **Measure, predict, and optimize complex systems.**
2) **Accelerate the development of sustainability solutions.**
3) **Empower the sustainability workforce.**

Measure, predict, and optimize complex systems

AI can enable people to discern patterns, predict outcomes, and optimize performance in systems that are too complex for traditional analytic methods. Sustainability practitioners are increasingly using AI's analytical power for measuring and managing systems. Consider wildfires, which release about 7 gigatons (Gt) of carbon dioxide a year to the atmosphere.[1] Wildfires are difficult to predict because of the complex interplay of many factors, including weather, vegetation, and land use. AI is enabling better wildfire prediction and making better management possible. At Microsoft, we are working with partners to use AI to help communities reduce wildfire risk.[2]

Accelerate the development of sustainability solutions

AI can accelerate the discovery and development of sustainability solutions such as low-carbon materials, renewable energy production and storage, and climate-resilient crops. While AI is already contributing to sustainability-related discoveries, its transformative potential is only beginning to be realized. However, AI's game-changing potential has already been demonstrated in other sectors.

For example, AI was instrumental in accelerating the development of vaccines that mitigated the severity of the COVID-19 pandemic. AI was used to screen candidate messenger RNA (mRNA) molecules, which allowed Moderna to produce an effective COVID-19 vaccine in only six weeks, compared with the four years it would have taken with traditional methods.[3]

Empower the sustainability workforce

AI can empower the sustainability workforce by enabling targeted training and assistance, while amplifying the efforts of sustainability professionals. We are working with partners to use large language models (LLMs) to access and distill the vast archives of sustainability science and policy documents so that sustainability professionals can easily find the information they need to understand and manage complex sustainability challenges.

In Part 1 of this report, we explore each of these three game-changing abilities in more detail.

Given the urgency of the planetary crisis, society needs to push harder on the AI accelerator while establishing guardrails that steer the world safely, securely, and equitably toward net-zero emissions, climate resilience, and a nature-positive future.

Microsoft's AI & Sustainability Playbook

The global technology, energy, and policy landscape is ripe to be primed to unlock AI's transformative potential for sustainability. This white paper introduces our five-point playbook for creating the needed enabling conditions.

1. **Invest in AI** to accelerate sustainability solutions
2. **Develop digital and data infrastructure** for the inclusive use of AI for sustainability
3. **Minimize resource use** in AI operations
4. **Advance AI policy principles and governance** for sustainability
5. **Build workforce capacity** to use AI for sustainability

These actions can unleash a flywheel for progress. AI can enable the development and deployment of sustainability solutions that accelerate decarbonization, which can enable the development of more sustainable AI operations, which in turn can enable AI to scale the deployment of more sustainability solutions. In Part 2 of this report, we describe this five-point playbook, summarized here.

1. Invest in AI to accelerate sustainability solutions

AI has numerous applications that can enhance efficiency, optimize business operations, and provide game-changing breakthroughs to sustainability bottlenecks. AI can help to expedite the integration of renewables onto electric grids, develop energy storage solutions, reduce food waste, foster the creation of high carbon-absorbing materials, and enable accurate weather forecasting weeks or even months in advance of current capabilities.

At Microsoft, through our AI for Good Lab, Microsoft Research's AI4Science Lab, and Microsoft Climate Research Initiative (MCRI), we are already applying AI to overcome large sustainability bottlenecks. For example, in one MCRI project, we are partnering with researchers at the Massachusetts Institute of Technology (MIT) and University of California, Berkeley (UC Berkeley) to use generative machine learning models to develop new materials and system engineering approaches for applications such as carbon capture. Through the Microsoft Climate Innovation Fund, we are investing in companies like LineVision that are using AI to expand the capacity of transmission lines.

2. Develop digital and data infrastructure for the inclusive use of AI for sustainability

Data is the foundation on which AI operates, shaping its insights, predictions, and decision-making capabilities. Yet, there are major gaps and accessibility challenges that constrain the development of accurate and representative AI models for sustainability. For example, while AI is critical for optimizing the world's electricity distribution networks, its use is limited by the availability of detailed, real-time data, which is lacking in many regions.[4] Or, consider biodiversity data, where 80 percent of data in the Global

Biodiversity Information Facility (GBIF) comes from just 10 countries.[5]

Even when data exists, it can be inaccessible or difficult to use because it is locked in institutional silos, not digitalized, or in incompatible formats. Data standards, sharing mechanisms, and platforms are needed to increase the usability of sustainability data in AI models.

To use the full potential of AI, sustainability solution providers need access to the internet and compute capacity. The Microsoft Airband Initiative is working with our global ecosystem of partners to bring internet access to 250 million people in unserved and underserved communities around the world by 2025, including 100 million in Africa.

3. Minimize resource use in AI operations

As the infrastructure needed to support AI models expands, demand for resources such as energy and water will rise. History suggests that innovation can curb that demand. Take datacenters, for example. Between 2010 and 2020, global datacenter workloads increased by approximately 940 percent, while datacenter electricity demand increased by only 10 percent.[6]

At Microsoft, we are continuously researching and innovating ways to make our datacenters and AI systems ever more energy and water efficient.[7,8,9] We are reducing our dependence on freshwater from municipal sources for datacenter cooling and investing in water replenishment in water-stressed basins. We have also been developing advanced cooling methods such as liquid cooling to support AI chips with lower energy and water overheads.[7,8,10] We have partnered with the Green Software Foundation to develop and advance carbon-aware software practices, such as software designed to run at times and locations that use the least carbon-intensive electricity sources available. These principles apply to all software workloads, including AI.

4. Advance AI policy principles and governance for sustainability

AI technologies can have a positive impact on both the environment and society by accelerating sustainable business practices and the energy transition. The infrastructure that hosts the computing power needed to yield these benefits may affect resource use too, such as by increasing power needs while reducing water reliance. Governments have an opportunity to enable the positive impacts of AI by crafting policies that harness its capabilities to benefit and ensure alignment with sustainability outcomes while also mitigating the resource impact that will result from the increased demand for AI.

At Microsoft, we will continue to use our voice to support grid decarbonization and carbon reporting, reduction, and removal policies. In September 2022, we outlined the priorities and principles that guide our advocacy on carbon and electricity policy around the world to accelerate carbon reporting, reduction, and removal and to expand carbon-free electricity.[11,12] We also intend to expand our advocacy for extending existing sustainability policy frameworks to include AI and aligning government policies to incentivize the use of AI to enable sustainability outcomes.

We also persist in our efforts to strengthen AI governance, helping to ensure trust among users, stakeholders, and the wider public—an indispensable basis for AI's integral role in advancing sustainability. As the application of AI expands into critical sustainability infrastructure, including power grids and water utilities, the safety, security, and reliability of these AI systems become paramount. We are committed to building and using AI responsibly, as recently outlined in our Governing AI report.[13]

5. Build workforce capacity to use AI for sustainability

To harness the transformative power of AI for sustainability requires a solid foundation of human capacity to use AI tools.

Building a workforce prepared to use AI for sustainability requires holistic learning pathways that cultivate AI fluency within the context of sustainability. To help people and communities around the world learn how to harness the power of AI, Microsoft recently launched a new AI Skills Initiative. We have also committed to bringing these AI skills to the sustainability workforce. Last year, we partnered with the global nonprofit INCO to launch a new Green Digital Skills certificate program to educate workers and jobseekers on the foundations of sustainability in technology and green design principles and practices. To date, 30,000 people from 140 countries have engaged in the certificate program.

Tracking AI's impact on the global race to net zero

To ensure that AI is on track to accelerate sustainability progress, it will be essential to continually assess AI's expected impact on the race to net zero. But this is not an easy task, as it requires projecting a range of interacting and uncertain factors, such as socioeconomic, policy, and technological developments.

Currently, AI compute accounts for only a fraction of the electricity used by datacenters, which collectively use about 1 percent of global electricity supply.[14] How much this increases and how AI growth affects the global race to net zero will depend on many factors. Innovations that drive efficiency gains in both the computing infrastructure and AI operations will have a large impact on future AI energy use. The carbon emissions implications of increased energy demand will depend on the broader policy context in which AI operates and how rapidly electric grids are decarbonized. And finally, AI's impact on the global race to net zero depends on how much it enables sustainability solutions.

In Part 3 of this report, we explore what is needed to better assess and track AI's impact on the global path to net zero. In particular, we highlight the importance of using scenario analysis to help inform and guide AI development for sustainability.

Understanding AI's impact on the global race to net-zero emissions requires answering three questions:

1. How much energy is the global expansion of AI compute likely to consume?
2. How fast will the world's electric grids decarbonize?
3. To what extent will AI enable sustainability solutions?

To use AI effectively to accelerate sustainability, businesses, governments, and civil society must work together to create the enabling conditions while continually monitoring the factors that will determine AI's impact on the world's race to net zero.

When we use it ethically and responsibly, AI can be an essential tool to accelerate progress toward sustainability. Together, we have the opportunity to ensure that it does. We invite you to join us in unlocking the accelerating power of AI for sustainability.

Brad Smith
Vice Chair and President

Melanie Nakagawa
Chief Sustainability Officer

Part 1

AI’s three game-changing abilities

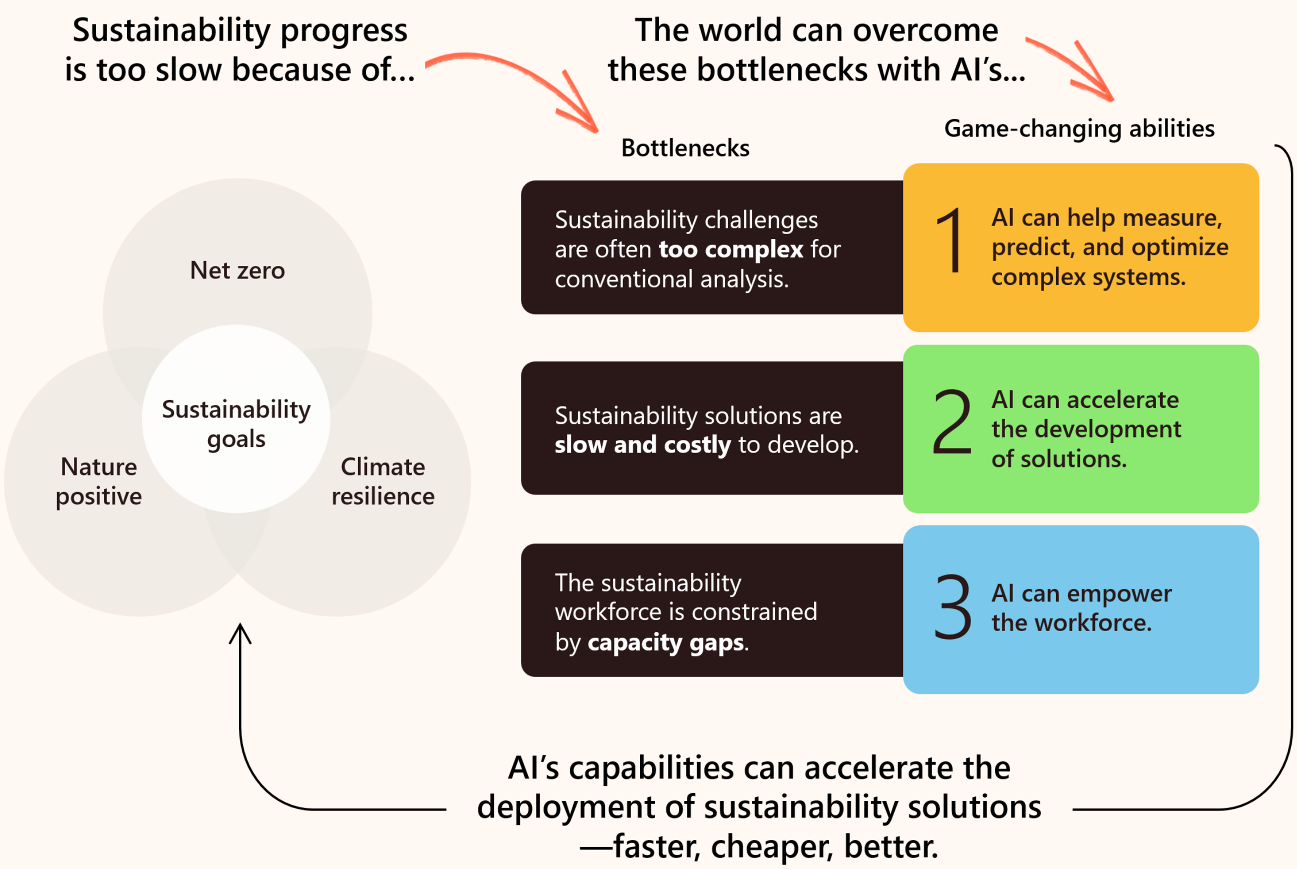
Recent advances in AI are transforming the way that computers can assist people in doing tasks and solving problems, making it possible to achieve things that were previously unattainable.

Traditional computer programs, including narrow AI models, solve problems by following detailed instructions written by programmers. These algorithms are inherently limited to the solutions already discovered by humans and are narrowly focused on a given task.

In contrast, many AI models today emulate aspects of human cognitive processes by learning from data and experience. They can generate original solutions without direct explicit instructions from humans.

The new expanding capabilities of AI align with what’s needed to overcome many bottlenecks that hinder progress toward climate and biodiversity goals. Examples include the complexity of systems that need to be managed, lengthy research and development cycles, and a large gap in capacity in the sustainability workforce.

In this section, we outline *three game-changing abilities* of AI technologies that can be used to accelerate the sustainability transition. We provide examples to illustrate how AI applications can overcome the bottlenecks that are limiting progress toward the three key global sustainability goals: achieving net-zero emissions, building climate resilience, and protecting and restoring nature.



Measure, predict, and optimize complex systems for sustainability

Sustainability solutions often hinge on comprehending and managing complex industrial, socioeconomic, and natural systems. These include systems such as supply chains, electricity grids, agricultural ecosystems, and the climate system. These complex systems are characterized by intricate webs of interconnected parts, where seemingly minor changes or disruptions in one part of the system can have ripple effects in seemingly unconnected parts of that same system.

The dynamics within complex systems can be counterintuitive and elude conventional analytic techniques. But AI excels in this realm because it can process enormous amounts of multimodal data and identify patterns, relationships, and signals of change that are beyond the ability of human analysts and classical statistical techniques to detect. As a result, AI can enable people to measure changes and predict and optimize the behavior of systems in ways that they were unable to do previously. These new capabilities can increase efficiencies, reduce waste, and facilitate the sustainability transition.

Following, we briefly outline three examples (with details provided in the appendix) of how AI is enabling people to better measure, predict, and optimize complex sustainability systems.

Increase capacity of electric transmission

One of the biggest constraints in integrating more renewable energy into electric grids is the limitation in grid transmission capacity. The Microsoft Climate Innovation Fund invested in LineVision, which uses AI to provide reliable hourly ratings of the current carrying capacity of transmission lines. This allows transmission line owners to unlock carrying capacity and bring on more renewables. National Grid UK used LineVision's patented sensing, AI, and advanced analytics capabilities to increase transmission line capacity by 60 percent. This has made it possible to add an additional 600 megawatts of offshore wind capacity.[15]

Reduce water leaks

Globally, 25–30 percent of drinking water is lost every year as a result of leakage from sprawling and often antiquated urban water distribution systems. AI sensors offer an innovative and scalable approach to reducing water loss and monitoring water usage across a distribution network. Microsoft has established a partnership with FIDO Tech to deliver AI-enabled leak detection and water-use monitoring in England, the United States, and Mexico.

Reliably track and manage biodiversity

Researchers and practitioners are using AI to enable more reliable biodiversity monitoring and assessments and transform conservation decision making with the analysis of real-time data and early warnings of ecological tipping points.[16]

The Microsoft AI for Good Lab is working with government agencies such as the U.S. National Oceanic and Atmospheric Administration (NOAA), conservation organizations such as The Nature Conservancy, and research universities around the globe to apply machine learning tools to accelerate ecologists' workflows such as biodiversity surveys.[17] Microsoft has also built the Planetary Computer, a platform that provides access to a multi-petabyte catalog of global environmental data, which can accelerate the development of sustainability solutions.

Accelerate the development of sustainability solutions

Many sustainability solutions are hindered by slow and costly research and development processes. For example, consider materials like steel, cement, and plastics, which together account for almost 20 percent of global carbon dioxide emissions.[18,19] Developing low-carbon alternatives for these materials or lower-carbon processes for developing them is critical to achieving net zero.

AI models are transforming the world's approach to materials engineering. AI models trained on datasets of basic material properties can rapidly sort through billions of possibilities and identify promising materials in a fraction of the time that would have been required for conventional empirical approaches.[20] Candidate compounds can then be tested with AI-run robotic laboratory experiments, in which AI programs also interpret the results and design follow-up experiments.[21,22]

The power of AI to transform scientific discovery is vividly illustrated by the recent breakthrough in predicting the structure of proteins—knowledge that is vital for creating targeted drugs and vaccines. Previously, several years of painstaking and costly work were required to map the structure of just one protein. But recently, an AI program, AlphaFold, reduced the time required from years to less than one minute.[23]

Following, we briefly outline three examples (with details provided in the appendix) of how researchers are beginning to use AI to seek similar breakthrough discoveries for sustainability.

Accelerate carbon-free energy production

AI is accelerating the development of new materials for capturing solar power that are more efficient in converting sunlight to electricity and are less costly to manufacture.[24] AI is also being used to unlock vast amounts of geothermal energy[25] by helping to optimize the design and operation of new geothermal power plants.[26] And although fusion energy remains years away from large-scale deployment, AI is hastening its arrival by learning to control high-power magnetic fields[27] and accelerating the search for new materials necessary to line reactor walls.

Accelerate development of lower-cost energy storage

Energy storage is key for integrating intermittent wind and solar power into electricity grids, but it is currently too expensive to deploy at the scale needed. Researchers are using AI to rapidly screen and predict material properties that could improve battery performance at a lower cost.[28,29] AI is also being used to scale and lower the cost of storing renewable energy as green hydrogen. For example, Microsoft AI and Azure Quantum capabilities are helping accelerate the identification of potentially cheaper catalysts for producing green hydrogen, reducing calculation times by up to 50 percent.[30]

Accelerate development of climate-resilient crops

Improving crop productivity and adaptability is critical for building resilience to climate change.[31] Conventional breeding technologies for crop improvements are slow, typically taking 7–12 years to develop new cultivars.[32,33] By enabling researchers to analyze large and complex datasets, simulate plant responses to environmental stressors, and identify genetic markers associated with desirable traits, AI can significantly fast-track the breeding process with increased accuracy and precision. AI is being used to safely accelerate this process for climate-resilient crops.[34]

Empower the sustainability workforce

To meet global sustainability goals, every company will need to fundamentally transform operations to significantly reduce greenhouse gas emissions and address other environmental concerns including water, waste, and ecosystems. Achieving this transformation will require a workforce that can design, drive, and track progress toward sustainability goals. Currently, there are not enough people with the required skills and know-how to deliver this transformation at the pace the world needs.[35] The sustainability workforce must grow, and quickly. While that happens, AI is emerging as both an enabler and force multiplier, empowering the workforce to work more efficiently and effectively to address the intricate challenges of sustainability.

Following, we briefly outline three examples (with details provided in the appendix) of how AI is providing transformative tools for empowering the world's sustainability workforce.

Specialized assistance

Using generative AI as a domain-specific copilot can be a game changer for productivity. For instance, the GitHub Copilot solution uses generative AI to assist developers in writing code, enhancing their productivity significantly by producing code up to 55 percent faster.[36] At Microsoft, we are working with partners to use generative AI to help practitioners distill the vast amount of information needed for sustainability work, empowering professionals to make more informed and impactful decisions. For example, researchers at Microsoft have demonstrated a virtual agronomist assistant capable of achieving a passing grade on exams to earn credits for renewing agronomist certifications.[37] This virtual assistant has the potential to help agronomists to stay up to date with the latest information and enable them to provide better advice, more efficiently, to the farmers whom they serve.[37]

Workflow optimization

In today's fast-paced work environments, repetitive and time-consuming tasks can hinder professionals from focusing on high-priority strategic activities. AI can be a powerful tool for automating repetitive tasks, dramatically improving the efficiency of workflows. AI-enabled automation is not just about task efficiency but also about optimizing human potential in the sustainability sector. Microsoft Cloud for Sustainability is building AI into many of our products and solutions to help customers quickly perform advanced analytics and generate detailed, actionable insights. AI will help companies make more impactful decisions toward net-zero goals through a new anomaly detection feature that will enable organizations to find outliers, trends, and correlations between their activity data and calculated emissions.

Individualized training

Traditional training modules often adopt a one-size-fits-all approach, potentially overlooking individual strengths and weaknesses. For example, Microsoft has embedded AI into its Reading Progress tool to allow teachers to create personalized reading passages based on the words or phonics rules that a class or specific student found most challenging.[38] Similarly, AI-enabled individualized training for sustainability professionals can be a powerful tool to address the sustainability skills gap.[35]

Part 2

Five-point playbook for enabling AI to accelerate sustainability

Five-point playbook...

1. **Invest in AI** to accelerate sustainability solutions
2. **Develop digital and data infrastructure** for the inclusive use of AI for sustainability
3. **Minimize resource use** in AI operations
4. **Advance AI policy principles and governance** for sustainability
5. **Build workforce capacity** to use AI for sustainability

...to unlock the flywheel for accelerating sustainability

While AI has the potential to accelerate the world's sustainability transformation, its success is not guaranteed. Establishing the right enabling conditions is critical. Without them, the world risks missing out on AI's full capacity to drive our sustainability aspirations forward. However, the right enabling conditions can initiate a self-sustaining cycle, akin to a flywheel, in which AI generates sustainability solutions that expedite decarbonization. This, in turn, promotes greater use of AI in support of sustainability.

Here, we offer a five-point strategy to help ensure that AI delivers on its potential as an accelerator for global sustainability, as well as details on the steps that Microsoft is taking to contribute to each part of this strategy.

1

Invest in AI to accelerate sustainability solutions

AI has numerous applications that can enhance efficiency and optimize business operations, particularly in addressing sustainability issues. While these applications offer significant value, the game-changing potential of AI lies in its ability to address critical bottlenecks such as by expediting the development of low-cost, long-duration energy storage solutions, fostering the creation of high carbon-absorbing materials, enabling more robust weather and climate forecasting, and empowering the sustainability workforce.

While some investments in AI for sustainability may not yield immediate financial returns, the benefits could be far-reaching and transformative. AI can not only overcome key bottlenecks, but it can also act as a catalyst for change, stimulating innovation, leading to novel solutions that benefit society and create new markets, and accelerating progress toward international sustainability goals.

To harness AI's full potential for sustainability, the public and private sectors must provide financial incentives and create opportunities to focus AI research and development efforts on addressing sustainability's biggest challenges. They must also foster partnerships and collaborations between AI experts and sustainability scientists.

In most cases, sustainability solutions will require cross-sector and cross-disciplinary collaborations. For example, integrating AI and Earth systems science together is helping to develop revolutionary models capable of better demonstrating the current state of the Earth and predicting how it might change in the future.[39]

Microsoft's approach

Through our AI4Science Lab and the Microsoft Climate Research Initiative (MCRI), we are building partnerships between AI researchers and sustainability experts around the world to tackle sustainability bottlenecks. For example, in one MCRI project, we are partnering with researchers at the Massachusetts Institute of Technology (MIT) and University of California, Berkeley (UC Berkeley) to use generative machine learning models to develop new materials for applications such as carbon capture.

Looking forward Microsoft will continue to look for opportunities to invest in and collaborate with partners to create AI solutions that:

- Accelerate emissions reductions, carbon removal, and the protection of nature. We will target our efforts at overcoming critical bottlenecks.
- Build climate resilience across vulnerable countries around the world, including in Africa and the Pacific. We will look to partner with governments, intergovernmental organizations, non-governmental organizations (NGOs), and the private sector to help use AI to identify the potential impacts of climate change on communities and the environment across these vulnerable regions.
- Foster the enabling conditions for harnessing AI in advancing sustainability science and innovation across key regions of the world. We will collaborate with the International Science Council's Center for Science Futures to assess the needs and opportunities.

2

Develop digital and data infrastructure for the inclusive use of AI for sustainability

For AI's promise in sustainability to be successful, it must be inclusive. This requires addressing the disparities in data availability, usability, and the technological resources that AI models depend on.

Data is the foundation on which AI operates, shaping its insights, predictions, and decision-making capabilities.[40] Despite the rapid growth in new data from satellites and Internet of Things (IoT) sensors, there are still major gaps in the world's environmental data, with uneven geographical coverage, and challenges in accessing the data that does exist. Overcoming these will require three major efforts.

First, there is a need to **invest in filling critical data gaps**, particularly in underrepresented regions of the world. Data gaps are widespread across many sustainability issues, with the UN Environment Programme (UNEP) estimating that 58 percent of environment-related indicators for the world's Sustainable Development Goals (SDGs) lack sufficient data to monitor progress.[41] In many cases, there simply isn't enough data collected. For example, the world's electricity distribution networks lack high-frequency, granular monitoring data, which is needed to build AI models to optimize the operation of these networks.[4] Similarly, global biodiversity data is not sampled at a high enough spatial resolution globally, with less than 1 percent of the planet sampled at a resolution of 1 square kilometer.[5]

These gaps in data are compounded by uneven spatial distribution of data, leading to global datasets that are not truly representative. For example, almost 80 percent of data in the Global Biodiversity Information Facility (GBIF) comes from just 10 countries, with countries with a higher gross domestic product (GDP) having better sampling coverage.[5] Similarly, climate adaptation data is often missing in the very countries that are most vulnerable, with the world's least developed countries (LDCs) and small island developing states (SIDS) having less than 10 percent of the basic weather and climate data needed to inform adaptation.[42] These issues around the representativeness of knowledge extend to the scientific literature that underpins global assessment reports undertaken by groups like the Intergovernmental Panel on Climate Change (IPCC). For example, 90 percent of the authors of the 100 most citied climate papers from 2016–2020 were affiliated with institutions in North America, Europe, or Oceania.[43] In contrast, less than 1 percent of authors were from Africa.[43] Unlocking AI for sustainability will require the world to invest in filling these data gaps with an emphasis on addressing the unevenness in coverage and accessibility.

Second, **AI-ready data standards** need to be established and adopted to enable effective use of available environmental data. One of the key opportunities for AI to accelerate the world's sustainability journey is through the integration of diverse data across domains like climate, water, biodiversity, and socioeconomics. However, the development of such integrative models is constrained by a lack of AI-ready data that has been cleaned, harmonized, formatted, and well documented.[44] This is due, in part, to a lack of either well-documented standards or domain-specific reporting formats that can support interoperability.[45] Take greenhouse gas emissions data, where the lack of clear standards focused on driving interoperability has led to a patchwork of greenhouse gas accounts across nations, companies, and scientists that cannot be compared or integrated.[46] Similarly, water, wildfire, and ecosystem data is collected by a wide range of sectors and jurisdictions and is fragmented across so many different platforms and data formats that it is difficult to find and use data for anything other than its original purpose.[47,48]

Even where there is AI-ready data, many attempts to apply AI modeling are hamstrung by infrastructure that does not enable analysis across domains.[44] Equally, to use AI to model environmental change, it needs to be able to access and meaningfully integrate data across a wide range of temporal and spatial scales.[49] Addressing these data accessibility and interoperability challenges requires building a cohesive digital infrastructure that enables the integration of diverse data types across domains. Efforts like the Microsoft Planetary Computer are helping to address this challenge by providing access to the world's critical environmental datasets and a computing platform to analyze those datasets on.

Third, **broad access to digital infrastructure is needed** to ensure inclusive use of AI for sustainability. Issues such as internet connectivity, cost of internet-enabled devices, and other symptoms of the world's digital divide are preventing many marginalized and disadvantaged communities from sharing in the benefits of AI for sustainability. The impacts of these challenges are clearly reflected in the most recent Government AI Readiness Index, which shows that many countries, particularly in sub-Saharan Africa, are lagging the rest of the world in their ability to take advantage of the AI revolution.[50]

For AI's promise in sustainability to be genuinely inclusive, efforts must be channeled to bridge the digital divide. This means creating infrastructure that is accessible, affordable, and adaptable to diverse needs. Empowering communities with digital tools can help ensure that AI-driven solutions can be developed by and provide tangible benefits to all.

Microsoft's approach

At Microsoft, we are helping to fill these gaps through our investments in world-leading environmental infrastructure, like the Planetary Computer, and through innovative partnerships such as our AI for Good Lab's work with Planet Labs PBC and The Nature Conservancy on Global Renewables Watch, which is building the world's first atlas of all utility-scale renewable energy installations. We are also supporting the intergovernmental Group on Earth Observations Biodiversity Observation Network (GEO BON) to develop new open tools and methods to enable governments and researchers to fill key biodiversity data gaps. The Microsoft Airband Initiative is working with our global ecosystem of partners to bring internet access to 250 million people in unserved and underserved communities around the world by 2025, including 100 million in Africa.

Looking forward Microsoft will work to fill critical data gaps, including by:

- Expanding our partnership with governments and public and private organizations to take advantage of AI in the design and implementation of the biodiversity observing networks needed to track and accelerate progress toward a nature-positive world.
- Integrating the Microsoft Premonition biological sensing and biological intelligence platforms into our Azure infrastructure—providing new tools to help quantify datacenter impacts on surrounding ecosystems.

3

Minimize resource use in AI operations

Currently, less than 1 percent of global electricity and water use is due to AI operations.[14] As the infrastructure needed to support AI models continues to be developed, electricity demand will rise, but it's difficult to predict by how much and what that growth will mean for greenhouse gas emissions. History has shown that innovation can lead to efficiencies and transformations that curb resource demand. For example, between 2010 and 2020, global datacenter workloads increased by approximately 940 percent, while datacenter electricity demand increased by only 10 percent.[6]

However, even as innovations and best practices lead to an eventual leveling off of global growth in resource demand for AI operations, without proactive action, the growth of AI could stress local electric grids and water resources in some regions where datacenter development is expanding to meet the needs of AI compute. This is because the local increase in demand can be large relative to existing electricity and water supply.

To continue to advance datacenter resource use efficiencies, sustained investments from the public and private sectors are needed. It's equally important to establish and adhere to best practices, ensuring optimal resource utilization in AI infrastructure and algorithm design and operations.

Microsoft's approach

Across the globe, Microsoft has been innovating in the design and operation of datacenters to conserve power and reduce emissions. Our latest datacenters have a design power use effectiveness (PUE) of 1.12, where the closer the PUE is to "1", the more efficient the use of energy.[51] We have also been developing advanced cooling methods such as liquid cooling to support AI chips with lower energy and water overheads.[7,10,8] In Finland, two new Microsoft datacenters are designed to harness their heat waste and contribute to the district heating system that provides warmth to Finland's second largest city, Espoo, and neighboring Kauniainen.[52] Similarly, the Microsoft datacenter region in Sweden uses rainwater and outside air to cool servers.[53]

Beyond efforts to reduce our energy demand, we are also entering into power purchase agreements (PPAs) that help to increase the carbon-free energy supply in areas where we operate. For example, last year in Ireland, Microsoft announced PPAs for more than 900 megawatts of new renewable electricity capacity.[54] We're also actively decreasing our reliance on municipal freshwater sources for cooling while concurrently investing in water replenishment in regions facing water scarcity. In California, our San Jose datacenters will be cooled year-round with an indirect evaporative cooling system that uses reclaimed water exclusively.[55]

Looking forward In addition to the work that we have already been doing, Microsoft will go further with our plans to:

- Operationalize the carbon-aware software practices that we have helped develop through our collaboration with the Green Software Foundation, emphasizing software optimized to use the least carbon-intensive electricity source.
- Increase our research and development of innovative approaches for improving datacenter energy and water efficiency.

4

Advance AI policy principles and governance for sustainability

AI technologies can have a positive impact on both the environment and society by accelerating sustainable business practices and the energy transition. The infrastructure that hosts the computing power needed to yield these benefits may affect resource use by increasing power needs while reducing water reliance, for instance. Governments have an opportunity to enable the positive impacts of AI by crafting policies that harness the capabilities of AI to help ensure alignment with sustainability outcomes while also mitigating the resource use that will result from the increased demand for AI.

As governments develop policies surrounding the sustainability of AI, Microsoft supports standardizing policy frameworks that, to the extent possible, apply globally. In markets where datacenter sustainability policies already exist, we encourage governments to include AI in existing sustainability policy frameworks. In the European Union (EU), for example, both the Energy Efficiency Directive, which sets rules and obligations for achieving the EU's ambitious energy efficiency targets, and the EU Taxonomy, which creates an EU-wide classification for sustainability activities, will require certain metrics to be reported out of datacenters and could easily be transposed to apply to facilities that host AI computing. Microsoft will continue to use our voice to support metrics that serve datacenter sustainability performance, broad grid decarbonization, carbon reporting, reduction, and removal policies, zero waste, and water positive objectives.

Accelerate the transition to carbon-free electricity grids. As detailed in Microsoft's electricity policy brief, Microsoft supports public policies that 1) accelerate the development of carbon-free generation, 2) modernize and improve grid infrastructure, and 3) enable an equitable future. The use of advanced digital technologies, including AI, can help expedite public policy implementation, remove impediments, and be used as a tool to help speed the transition to a decarbonized grid. AI can enable faster decision making for power grid resource and transmission planning and speed permitting decisions and the grid interconnection process for critical clean energy assets. Moreover, AI could increasingly become the basis of data science-led approaches for operating the clean energy grid of the future, and utilities, balancing authorities, and their regulators will need policy means for including AI in power system management.

Build on existing sustainability policy frameworks to include AI. AI is powered by datacenters. Microsoft supports policies that 1) align environmental impact disclosure and requirements for AI foundation models with existing and emerging energy and sustainability regulations; 2) focus on clear and consistent government policies related to performance standards; and 3) are designed in consultation with industry and other stakeholders, including the tools used to comply with those regulations. As governments update existing frameworks—or create new frameworks where they don't yet exist—we encourage policymakers to prioritize integrating AI into standards and metrics that currently regulate datacenter carbon, energy, waste, and water efficiency and sustainability performance. Additional considerations include energy efficiency; component modularity; sustainable production practices for AI hardware manufacturers extending circularity; proper recycling and disposal to reduce electronic waste requirements in AI devices; and encouraging corporate carbon reduction targets to include AI resource use as a factor in AI infrastructure design and operations, including through carbon footprint accounting and reporting.

Sustainability policy should recognize that there is not a standard definition of AI infrastructure, in part because AI remains a nascent, fast-developing field in terms of both software and hardware and because it will often rely on infrastructure that hosts other types of workloads. As such, aligning AI infrastructure to existing standards in practice in the information and communications technology (ICT) sector and creating regulatory space for innovation and AI-specific performance-based scoring in sustainability reporting would balance the need for putting sustainability front and center without compromising technical progress.

Align government policies to incentivize the use of AI to enable sustainability outcomes. Governments play a pivotal role in providing incentives, making investments, and creating an enabling environment for using AI for sustainability outcomes. Microsoft supports the establishment of policy incentives that:

- Prioritize and fund the development of AI applications that directly contribute to environmental sustainability, such as climate modeling, carbon reporting, pollution monitoring, sustainable agriculture, reducing water consumption, energy efficiency, waste management, and carbon-free energy integration.
- Facilitate collaboration and partnerships among AI researchers, scientists, and policymakers by creating a regulatory sandbox to address sustainability challenges collaboratively and by funding interdisciplinary projects that combine AI expertise with policy, sustainability, and social justice.

- Foster global collaboration on a common policy framework for aligning the environmental footprint of AI with existing datacenter sustainability guidelines and standards and sharing best practices on use cases for AI to enable sustainability outcomes.

Our global sustainability policy work will build on existing advocacy efforts underway across the EU and globally.

Govern AI to help ensure that it is safe, secure, and trusted. As AI becomes more widespread, governments and companies like Microsoft are working to regulate it to help ensure that it is safe, secure, and trustworthy.[56,13,57] This is essential to enable AI to safely optimize and increase the efficiency of critical sustainability infrastructure systems such as electricity grids and complex water utilities. A malfunction in an AI-driven sustainability management system has the potential to disrupt vital operations and cause significant damage. To help ensure that these systems are secure, AI developers will need to follow industry best standards and implement and build upon government-led AI safety frameworks such as the US National Institute of Standards and Technology (NIST)'s AI Risk Management Framework.

Similarly, AI models have the potential to transform the monitoring and assessment of ecosystems.[58] However, as highlighted in the next point, existing ecosystem datasets have major gaps and spatial sampling biases[5] that must be identified, measured, and mitigated to reduce the chance that AI models provide misleading and unrepresentative assessments.

Finally, for AI to effectively scale and accelerate sustainability progress, it must be trusted by its users, stakeholders, and the broader public. At the heart of trust is accountability and transparency. To be trusted, AI systems used for sustainability will need to provide transparent and accessible documentation of the systems' capabilities, limitations, intended uses, and potential risks. This will also require the developers of models to engage with the communities that will be affected by AI-informed decisions to ensure that they can understand how decisions are being made.

Microsoft's approach

In September 2022, Microsoft outlined the priorities and principles that guide our advocacy on carbon and electricity policy around the world to accelerate carbon reporting, reduction, and removal and to expand carbon-free electricity. Microsoft will continue to use our voice to support grid decarbonization and carbon reporting, reduction, and removal policies.

With regard to governing AI, Microsoft has a long history of building a culture of responsible AI, as recently outlined in our Governing AI report and in the voluntary commitments we have made to help advance safe, secure, and trustworthy AI.[13,59] By prioritizing the governing of AI to help ensure its safety, security, and trustworthiness, we can cultivate AI as a copilot in the mission to advance sustainability.

Looking forward Microsoft will seek to:

- Use our voice to support metrics that serve datacenter sustainability performance, grid decarbonization, and carbon reporting, reduction, and removal policies.
- Build on existing sustainability policy frameworks to include additional applications for AI.
- Align with and support government policies to incentivize the use of AI to enable sustainability outcomes.
- Align Microsoft's environmental sustainability and responsible AI governance with Measure 2.12 of NIST's AI Risk Management Framework, which states that the "environmental impact and sustainability of AI model training and management activities … are assessed and documented."

5

Build workforce capacity to use AI for sustainability

To harness the transformative power of AI for sustainability requires a solid foundation of human capacity to use AI tools and the robust digital infrastructure to support them. Just as a car's potential to provide safe transport is realized by a skilled driver on well-paved roads, AI's potential to accelerate sustainability is maximized when steered by informed professionals and supported by state-of-the-art digital platforms.

AI offers the potential to help support the world's limited sustainability workforce, which is already suffering from major skills gaps.[35] However, unlocking AI's potential is dependent upon this already-stretched workforce having the skills and knowledge to use AI effectively and appropriately. This need is illustrated in the World Economic Forum's *2023 Future of Work Report*, which identified AI, machine learning, and sustainability specialists as the top three fastest growing roles.[60] Building a workforce able to use AI for sustainability requires holistic skilling pathways that cultivate AI fluency within the context of sustainability.

Microsoft's approach

To help people and communities around the world learn how to harness the power of AI, Microsoft recently launched a new AI Skills Initiative. This includes free coursework; an open global grant challenge in coordination with data.org to uncover new ways of training workers on generative AI; and greater access to free digital learning events and resources for everyone to improve their AI fluency. As workers advance their skills, they can progress to technical AI skilling on the Microsoft Learn platform. Learners can also build their skills through the Career Essentials for Sustainable Tech Learning Pathway by Microsoft and LinkedIn.

We are committed to bringing AI skills to the sustainability workforce. Last year, we partnered with the global nonprofit INCO to launch a new Green Digital Skills certificate program to educate workers and jobseekers on the foundations of sustainability in technology and green design principles and practices. To date, 30,000 people from 140 countries have engaged in the certificate program.

Microsoft is continuing to build the sustainability talent pipeline through partnerships with organizations such as UNESCO and the Association for the Advancement of Sustainability in Higher Education. Additionally, Minecraft Education provides game-based learning with targeted lessons that teach students how to use AI to address sustainability challenges.

Looking forward Microsoft will expand our work by continuing to help build the skills needed to unlock AI for sustainability for 100,000 learners by 2025, including by:

- Establishing a new AI for Sustainability Skilling course that will be added to the Career Essentials in Sustainable Tech Learning Pathway.
- Increasing our investment with our partner INCO to expand the Green Digital Skills certificate program, including by adding the new AI for Sustainability and Carbon Accounting modules.
- Continuing our investments in student skilling through Minecraft Education.
- Catalyzing the next generation of entrepreneurs to use AI to solve sustainability challenges through efforts like the Microsoft Imagine Cup. This global technology startup competition helps student entrepreneurs accelerate their vision and learn essential AI, entrepreneurial, and technical skills.

Part 3

Tracking AI's impact on the global race to net zero

It is important to develop a holistic understanding of AI's overall impact on sustainability. AI operations use resources with potential impacts on greenhouse gas emissions. But AI also has the power to help accelerate the world's sustainability transition. A holistic view is critical so that the world can put in place and adjust the strategies and guardrails needed to ensure that AI is helping to accelerate sustainability.

AI's impact on the race to net zero can't be assessed by answering narrow, simplistic questions such as how much energy is consumed in training one AI model. Ensuring that AI has an overall positive impact on sustainability requires a holistic understanding of how the growth in AI will affect global emissions in coming years.

That understanding will come from answering the right questions. Specifically, given innovation and policy trends and growth in demand:

1. How much energy is the global expansion of AI compute likely to consume?
2. How fast will the world's electric grids decarbonize?
3. To what extent will AI enable sustainability solutions?

Q1: How much energy is the global expansion of AI compute likely to consume?

Currently, AI compute accounts for only a fraction of electricity use by datacenters, which collectively use about 1 percent of global electricity supply.[14]

In recent years, dramatic improvements in energy efficiency have kept datacenter energy use remarkably stable, despite explosive growth in computing demand. For example, between 2010 and 2020, global datacenter workloads increased by approximately 940 percent, while datacenter electricity demand increased by only 10 percent.[6] Similarly, between 2010 and 2018, global server storage capacity grew eight times faster than global storage energy use.[75]

Additional datacenter infrastructure efficiency may become harder to achieve in coming years because much of the low-hanging fruit has already been harvested. However, there is great potential for AI-related efficiency gains from more efficient algorithms, streamlined training, innovations in cooling system designs, AI-specific graphics processing units (GPUs), and other AI accelerators,[61,62] as well as breakthroughs in processing technologies such as quantum and optical computing.[63,64,65] Growth in AI energy use will depend on the efficiency gains realized from each of these innovations and the tradeoffs between them.

Q2: How fast will the world's electric grids decarbonize?

AI's emissions footprint depends on the carbon intensity of the electricity that powers it and the carbon embodied in the supporting infrastructure. Even if AI growth drives large increases in energy demand, its impact on global carbon emissions will be limited if datacenters (and the supply chains that serve them) are powered by carbon-free energy. Much of the carbon embodied in data servers and processors will also be mitigated by decarbonizing the energy used in their fabrication. Similarly, the majority of the water use attributable to datacenters is because of the water required for electricity generation rather than direct use for datacenter cooling.[66,67] This can also be mitigated by decarbonizing the grids that power datacenters.

Today, the carbon intensity of electricity grids serving datacenters and their supply chains varies tremendously depending on location. For example, grid carbon intensity is 503 grams of carbon dioxide equivalent per kilowatt-hour (gCO_2e/kWh) in Australia but only 29 gCO_2e/kWh in Iceland.[68] Fortunately, the global supply of renewable energy is growing at an increasing pace. Between 2022 and 2027, renewables are forecast to account for over 90 percent of the growth in global electricity capacity, an 85 percent increase from the previous five years.[69]

Despite the progress underway, much more is needed. In coming years, the pace and scale of grid decarbonization will depend on a range of economic, technical, and political issues, such as the cost and availability of low-carbon technologies, financial incentives for clean energy adoption, transmission and storage infrastructure for renewable energy integration, strong environmental policies, international cooperation on climate goals, and public support for decarbonization initiatives.[70]

Q3: To what extent will AI enable sustainability solutions?

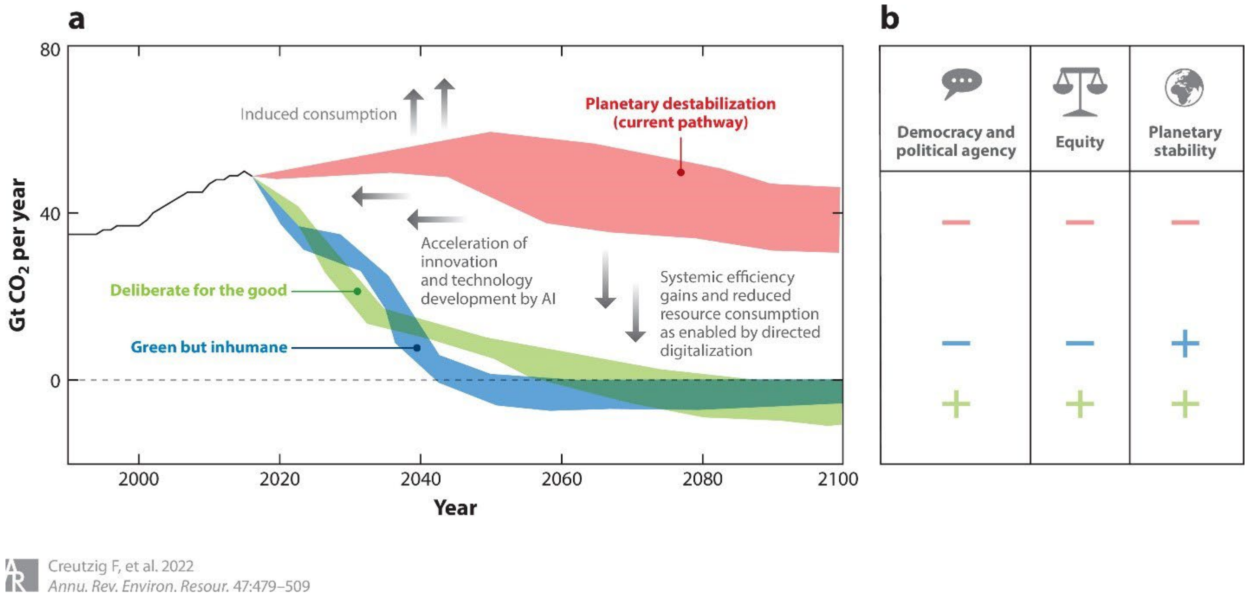
AI applications can drive operational and system changes that lead to reductions in emissions, both directly and indirectly.[71] For example, AI applications will likely play an increasingly critical role in accelerating decarbonization of electricity grids by integrating and managing distributed and variable renewable energy sources. AI applications will increasingly optimize supply chain logistics, helping to reduce transportation emissions. They can enable more efficient use of resources in manufacturing, reducing energy consumption and waste, thereby lowering emissions. Estimates of efficiency gains from AI-enabled global emissions reductions range from 4 to 10 percent by 2030.[72,73] Emissions reductions could be much greater if AI leads to breakthroughs, such as in the development of higher performance energy storage solutions, greater access to renewable energy sources, and low-carbon materials.

While AI can be used to make carbon-free energy more available and competitively priced, it can also be used to increase efficiencies in fossil fuel production, both cost and emissions. The net implications of these efficiency gains for the global journey to net zero will depend on a range of socioeconomic and policy conditions.

Quantifying and predicting both the emissions and emissions reductions enabled by AI is difficult; however, capturing these effects is critical when assessing how AI will influence future emissions.[71] This will require new research methods to compute net effects[74] and investments in data measurement and reporting systems.

The need for holistic AI climate scenarios

Large uncertainties surround the technological, economic, social, and political factors that will determine the future energy demand of AI models, the carbon intensity of the electricity that powers them, and the emissions reductions enabled by their use. Scenario analysis is a powerful tool for characterizing possible futures in the face of large uncertainties. For example, the IPCC analyzes future emissions and the potential impacts of climate policies with a set of scenarios that capture possible pathways for technological, economic, and social change. Scenario analysis should also be used to assess the impact that the growth in AI may have on future emissions.



This figure shows three possible future scenarios for how AI, and digitalization more broadly, could shape humanity's future.[75] The three scenarios all highlight the accelerating power of AI in driving societal change, each characterizing different outcomes. Planetary destabilization: AI and other digital technologies increase efficiency but also increase energy demand and resource consumption, undermine democratic deliberation, and increase inequality. Green but inhumane: AI and other digital technologies accelerate the deployment of renewable energy and increase efficiency while avoiding overconsumption, but with constrained human agency. Deliberate for the good: AI technologies are used efficiently and effectively, with trusted governance and practices. ($GtCO_2$ = gigatons of carbon dioxide.)

Researchers have highlighted that AI and digitalization more broadly could accelerate the world along multiple alternative pathways, with profound consequences for planetary stability, equity, and democracy. This is illustrated in the preceding figure from a recent scientific publication in the *Annual Review of Environment and Resources*[75] that considered three conceptual scenarios for the future. Which of these scenarios is realized will depend, in large part, on the choices made by society about investments, partnerships, and governance.

Assessing the implications of AI on the world's journey to net zero will require a scenario-based approach to explore how multiple uncertain factors may evolve and interact to shape alternative futures. It is also essential to take a holistic approach, considering both the potential emissions generated by building and operating AI models and the emissions implications of the use of AI applications.[76,71]

Looking forward Microsoft will partner with international researchers and institutions to advance the development of a holistic framework for tracking the impact of AI on the race to net zero.

Conclusion

Accelerating sustainability with AI together

The pace and scale of change needed to meet the world's sustainability goals is unprecedented in human history. Fortunately, AI has unprecedented potential to accelerate this transformation and help avoid an environmental catastrophe. However, action must be taken to realize AI's full potential to drive a flywheel effect, accelerating sustainability. In this report, we have outlined a five-point playbook for establishing the enabling conditions needed to use AI ethically and responsibly to accelerate the global sustainability transition.

If we work together, we can unlock AI's game-changing abilities to help create the net-zero, climate-resilient, and nature-positive world that we so urgently need.

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Appendix: Use cases

Following is an overview of examples of how AI is being used to accelerate and scale sustainability progress. Many of these were mentioned briefly, earlier in this report. These examples are organized by AI's three game-changing capabilities.

1) Measure, predict, and optimize complex systems for sustainability

How AI is enabling reduction of food waste

The food we waste is responsible for roughly 8 percent of global emissions,[77] with the UN reporting that in 2021 the world lost 13.2 percent of its food along the supply chain between farmers and consumers and a further 17 percent collectively wasted by households, food services, and retailers.[78] There is huge potential for AI to help tackle this problem, and progress is already being made. AI can provide improved tools for sorting and grading food quality, thereby reducing the quantity of food that is subsequently discarded because it is deemed of insufficient quality.[79,80] AI can also better forecast food demand, helping to ensure that the right amount of food is available when and where it is needed.[81] AI can be used to optimize the routing of food transportation networks to reduce emissions and costs and improve the quality of food.[82,83] It can also be used to better understand the behavioral causes of food waste at the retailer and consumer level and help the design of effective interventions to reduce this waste.[84]

At Microsoft, we're also helping customers and partners to use AI to monitor the status of fruits and vegetables on their shelves and enabling them to prioritize and promote these items for sale.[85]

How AI can help to feed the world with fewer resources

By 2050, to feed a population of almost 10 billion people, the world needs to produce 50 percent more food[86], and do so as the changing climate is making growing conditions in many places more challenging due to more volatile and extreme weather and expanding pests. This will require new approaches to farming that can produce more food while using fewer resources like land, water, and fertilizers.

Microsoft Farmvibes.AI is an open-source software package developed by Microsoft Research that provides a cutting-edge AI solution that helps farmers optimize their practices by fusing and analyzing datasets from satellites, drones, and local sensors. Microsoft AI is used to analyze this wealth of data to provide farmers with actionable insights on crop and soil health, resource utilization, pest and disease detection, and carbon footprint that can then allow farmers to produce more food while using fewer resources.

How AI is transforming weather forecasts

Recent advances in seasonal and subseasonal weather forecasting illustrate the ability of AI programs to predict the behavior of complex systems far better than what's possible with current modeling techniques. For example, a deep learning model trained on simulations of past sea surface temperatures can now accurately predict the onset and intensity of El Niño climate events up to nine months in advance, dramatically outperforming classical physics-based models.[87] Similarly, an AI model trained to correct biases in a conventional weather-forecasting model doubled the accuracy of forecasts looking out two to six weeks in the future.[88] These leaps in predictive accuracy will be valuable in many sectors, such as electric power, where better forecasts are needed to optimize renewable energy integration and reduce outages from extreme weather.

At Microsoft, we have announced a flexible and generalizable deep learning model for weather and climate science. ClimaX is trained on regional and global weather datasets, combined with climate model projections, and can be finetuned to forecast weather and climate across time scales from seasonal (months) and subseasonal (weeks) to short range (days) and nowcasting (hours).[89] Microsoft has shared ClimaX publicly with the goal of allowing anyone to easily use the latest machine learning methods to address a multitude of climate and weather modeling and forecasting problems.

How AI is enabling the integration of renewable energy onto electricity grids

The global transition to renewable energy will need AI technology to manage increasingly decentralized grids reliant on variable renewable energy sources. Traditional approaches to grid optimization, which use sensors, control systems, and conventional data analytics to balance supply and demand, are ill-equipped to handle the greater variability and intermittency of renewable and distributed energy sources, as well as increasing weather volatility.[90] AI algorithms can optimize grid management with variable and decentralized sources by analyzing data on weather patterns in real time, predicting supply and demand, and automating the control of energy storage and distribution systems.[91,92] AI can also improve the forecasting of renewable energy generation[93,94] and the design of real-time pricing strategies.[95] By seamlessly integrating diverse power inputs, AI can facilitate real-time optimization of energy distribution and help guarantee consistent electricity supply to consumers.

The application of AI to help build more reliable and greener electricity grids is still in its early stages, and further research and development are needed to determine how best to integrate AI as an effective copilot for better grid management and to safely enable split-second operating decisions in grid emergencies.[96,97] At Microsoft, we are using AI to design new approaches to distribute computing loads in datacenters to meet the availability of renewables.[98]

How AI is helping cities save scarce drinking water through leak detection and monitoring

Despite great progress, billions of people still lack access to water for drinking, sanitation, and hygiene.[78] Globally, 25–30 percent of drinking water is lost every year as a result of leakages in urban water distribution systems.[99]

AI sensors offer an innovative and scalable approach to reducing water loss and monitoring water usage across a distribution network. In recognition of the technology's potential as a water stewardship resource, Microsoft has launched a partnership with FIDO Tech to deliver AI-enabled leak detection and water management solutions for several water utilities, with projects in London, England; Phoenix, Arizona; and Querétaro, Mexico. The partnership is in its first phase with UK utility Thames Water in London, England, helping to drive down a 24 percent loss of input water volume to leakage. In Phoenix, Arizona, one of the driest regions in the United States, Oldcastle Infrastructure will deploy the technology across 350 km of the water pipeline network operated by EPCOR, Arizona's largest private utility. The latest collaboration with Generagua, experts in infrastructure solutions in water, will deploy the AI technology across 350 km of pipelines in the Querétaro metropolitan area, one of the six states suffering from droughts in Mexico.

FIDO AI uses network-embedded AI acoustic sensors to identify and determine the size of leaks, providing valuable information on where, when, and how much water loss is happening. The sensors continue reporting data after repairs have been made, showing whether the repairs are valid and how much water is saved. Continuous AI-enabled monitoring not only prevents leakage but also provides insight into how a network reacts in times of drought or high demand. It can help water utilities optimize water usage across the distribution network.

How AI is revolutionizing disaster early warning and response systems

Early warning of extreme climate events saves lives and reduces economic losses. Given the increasing frequency and intensity of extreme storms, wildfires, and heatwaves, there is an urgent need to protect every person on Earth with early warning technology.[100] The United Nations Early Warnings for All Initiative is pivotal in achieving this goal, and Microsoft is committed to contributing our capabilities to support this effort.

AI is needed to overcome two critical bottlenecks that prevent the development of affordable and effective early warning systems. First, traditional, process-based approaches to modeling hazards like extreme rainfall are often unable to provide information at a high enough spatial resolution and with enough lead time to allow people to take appropriate action to protect themselves. Second, these approaches cannot handle the complexity of integrating diverse information, such as uncertain predictions of hazards and incomplete datasets of exposures and vulnerabilities, to estimate the likely impacts and initiate action to protect those most vulnerable.[101,102] These limitations are particularly acute in Africa, which is disproportionately vulnerable to catastrophic weather yet has only one-tenth as many weather radar stations as Europe.[103]

AI can dramatically improve the prediction of extreme events and outperform state-of-the-art process-based models by enabling high-resolution probabilistic predictions orders of magnitude faster and at greatly reduced cost, while providing better information to decision makers than traditional approaches.[104,105,106] A key advantage of AI is its ability to automate the acquisition and improve the quality of socioeconomic exposure and vulnerability datasets. AI can also expand the geographical data coverage by enabling the transfer of learnings from data-rich regions to poorly observed ones.[107,108]

At Microsoft, we are collaborating with government, research, and civil society groups to apply AI to support early warning systems and responses to climate risks. In collaboration with SEEDS, our AI for Good Lab has developed an AI model to predict the impact of cyclones and heatwaves on local communities and buildings.[109] As part of the Microsoft Climate Research Initiative, researchers are using AI to strengthen subseasonal climate forecasting and enable bespoke "what-if" analysis for decision making on food security in Africa[110] under a changing and increasingly volatile climate.

How AI is transforming humanity's capacity to track and manage biodiversity changes

The world's biodiversity is declining at an unprecedented rate as a result of increasing pressures from land use change, pollution, invasive species, and climate change. Roughly 1 million species already face extinction, many within decades.[111] To halt and reverse biodiversity loss requires early detection of changes and an understanding of the drivers of change and local conditions to inform a response. AI can be used to monitor and track changes in biodiversity, fill knowledge gaps about how the natural environment is changing, and explore the implications for the economy and human wellbeing.[17] AI is already beginning to transform conservation decision making by analyzing real-time data and providing early warnings of ecological tipping points.[16] More broadly, AI is becoming increasingly important in modeling environmental change. Research suggests that combining data-driven AI methods with traditional process-based models can provide a more accurate representation of the Earth system than either approach is capable of alone.[39]

At Microsoft, our AI for Good Lab is collaborating with Universidad de Los Andes, the Humboldt Institute, and the Sinchi Institute in Colombia to apply machine learning with geospatial, bioacoustics, and computer vision data for conservation of the Amazon rainforest and its biodiversity. By monitoring changes in the forest with satellite imagery and terrestrial data, we're accelerating the work of local conservationists by helping them better understand the interconnectedness of the forest and its wildlife. AI for Good Lab also partners with government agencies such as the U.S. National Oceanic and Atmospheric Administration (NOAA), conservation organizations such as The Nature Conservancy, and research universities around the globe to apply machine learning tools to accelerate ecologists' workflows such as biodiversity surveys.[17] Microsoft has also built the Planetary Computer, a platform that provides access to a multi-petabyte catalog of global environmental data, which can accelerate the development of sustainability solutions.

2) Accelerate the development of sustainability solutions

How AI is accelerating carbon-free energy production

Solar has become one of the least expensive sources of new electricity-generating capacity, and yet photovoltaic technology still has tremendous potential for improvement. AI is accelerating the development of new materials that are more efficient in converting sunlight to electricity and are less costly to manufacture.[24] For example, one innovative approach is replacing silicon with other materials when making solar cells. The Microsoft AI for Good Lab has collaborated with a global consortium of researchers to develop AI models that can accelerate experimental screening of novel energy devices and architectures by forecasting and explaining the sources of degradation in solar cells.[112]

Geothermal energy potential is huge but currently underutilized.[25] Vast reservoirs of heat energy lie beneath Earth's surface, which can be converted to usable power by using this heat to create steam that can drive electric turbines. However, geothermal power development has lagged because of the difficulty and high cost of characterizing 3D geothermal reservoirs. AI and machine learning have the potential to transform these data-intensive tasks, reducing costs and increasing accuracy, while also helping to optimize the design and operation of new geothermal power plants.[26]

Nuclear fusion, the process that powers the sun, could provide abundant energy without the long-lived radioactive waste produced by conventional nuclear fission reactors. Researchers recently achieved an important milestone by extracting more energy from a fusion reaction than was used to trigger it.[113] AI has the potential to drive additional breakthroughs in the containment of materials during the fusion process.[27] AI is also accelerating the search for new materials to line reactor walls that can withstand movement of neutrons produced in the fusion reaction. Although fusion energy remains years away from large-scale deployment, AI can hasten its arrival.

How AI is accelerating the development of lower-cost improved energy storage

Currently, renewable energy accounts for approximately 30 percent of global power generation. According to the International Energy Agency (IEA), reaching net-zero emissions by 2050 will require renewable energy to grow to 60 percent of power generation by 2030.[114] Energy storage is essential to enable the scaling up of integration of variable wind and solar sources onto the electric grid. Currently, one of the most widely used technologies is pumped-storage hydropower, but this is costly and can only be installed in certain locations.

Batteries are playing a growing role as they can be installed anywhere;[115] however, scaling battery storage is constrained by the rising cost and limited supply of lithium and cobalt, key minerals used in battery production.

Researchers are using AI to design better batteries for long-term storage and to accelerate the development of new sustainable energy storage materials.[116,117] AI is used for rapid screening and prediction of materials properties that could improve battery performance through increased energy density, charge time, and cycle life.[28,29] New AI-designed batteries made without lithium and cobalt have become commercially available.[118]

Another option for storage of renewable energy is green hydrogen, which is hydrogen produced by electrolysis using carbon-free energy.[119,120,121] However, scaling the use of green hydrogen for energy storage is constrained by several factors, including the efficiency of electrolyzers and the durability of their components. Traditional electrolyzers often rely on expensive catalysts like platinum or iridium oxide and have exchange membranes that degrade over time. AI can help by accelerating the discovery of novel catalysts that might outperform or replace these expensive metals, thereby enhancing efficiency and reducing costs. Furthermore, AI can help expedite the prediction and validation of new, more resilient materials for membranes, helping to ensure longer lifespans and consistent electrolysis rates.

Microsoft AI and Azure Quantum Elements have enabled partners to speed up hydrogen fuel cell innovation, accelerating certain quantum chemistry calculations and reducing the turnaround time for scaled workloads from six months to a week.[30]

How AI is accelerating the development of climate-resilient crop varieties

Improving crop productivity, sustainability, and adaptability is critical for building resilience to climate change.[31] Conventional breeding technologies for crop improvements are slow, typically taking 7–12 years to develop new cultivars.[32,33] AI is being used to safely accelerate this process for climate-resilient crops[34] and the development of resilient plant varieties.

By enabling researchers to analyze large and complex datasets, simulate plant responses to environmental stressors, and identify genetic markers associated with desirable traits, AI has the potential to significantly fast-track the breeding process with increased accuracy and precision. This can lead to the development of plant varieties with better crop yields and increased resilience to environmental stressors, including drought, extreme heat, and pests.[34]

How AI is accelerating sustainable plastic development

Conventional plastics made from fossil fuels contribute significantly to greenhouse gas emissions while an explosion of plastic waste degrades habitats on land and in the ocean. Academic collaboratives such as the Acceleration Consortium are applying AI tools to accelerate the discovery of alternatives to conventional plastic. At Microsoft, researchers at the AI4Science Lab are working with the University of Washington to use generative AI models to design recyclable plastics to replace specialized single-use plastics used in printed circuit boards.

3) Empower the sustainability workforce

How AI can empower the workforce with specialized assistance

Using generative AI as a domain-specific copilot can be a game changer for productivity. For instance, the Microsoft Security Copilot is an AI assistant for security teams that helped our preview customers save up to 40 percent of their time on core security operations tasks with capabilities such as writing complex queries based only on natural language questions and summarizing security incidents. In the world of software development, the GitHub Copilot solution uses generative AI to assist developers in writing code, enhancing their productivity significantly by producing code up to 55 percent faster.[36] Today, workers can begin their journey with the introductory Generative AI learning path by Microsoft and LinkedIn and pursue domain-specific content at Microsoft Learn.

AI assistants are just beginning to be developed for the sustainability sector. For example, researchers at Microsoft have demonstrated a virtual agronomist assistant capable of achieving a passing grade on exams to earn credits for renewing agronomist certifications.[37] This virtual assistant has the potential to help agronomists to stay up to date with the latest information and enable them to provide better advice, more efficiently, to the farmers whom they serve.[37] More broadly, AI assistants can help distill the vast amount of information needed for sustainability work, empowering professionals to make more informed and impactful decisions.

How AI can empower the workforce with workflow optimization

In today's fast-paced work environments, repetitive and time-consuming tasks can hinder professionals from focusing on high-priority, strategic activities. One of the major barriers to the ability of companies to measure and reduce their environmental impacts is the manual and time-consuming nature of collecting, integrating, and interpreting data from across their operations and value chain. Data on key sustainability issues like emissions, biodiversity impacts, and water use tend to be siloed across multiple, often proprietary systems that don't lend themselves to easy integration or interoperability. AI can be a powerful tool for automating these tasks, dramatically improving efficiency. AI can also automate data collection from sensors and images, streamline the processing of vast environmental datasets, and even generate preliminary sustainability reports. For example, analyzing water samples for contaminants or monitoring air quality across regions can be automated using AI-driven sensors and systems. By handling the groundwork, AI not only helps ensure accuracy but also frees up sustainability experts to strategize, innovate, and make decisions based on the processed information. AI-enabled automation is not just about task efficiency but also about optimizing human potential in the sustainability sector.

One example of how Microsoft is using AI to advance task automation is the Microsoft Cloud for Sustainability, which is building AI into many of its products and solutions to help customers quickly perform advanced analytics and generate detailed, actionable insights. AI will help companies make more impactful decisions toward net-zero goals through a new anomaly detection feature that will enable organizations to find outliers, trends, and correlations between their activity data and calculated emissions.

How AI can empower the workforce with individualized training

Traditional training modules often adopt a "one-size-fits-all" approach, potentially overlooking individual strengths and weaknesses. With AI, training can be tailored to the unique needs of each employee. The transformative potential of such tools is evident in the education sector. For instance, Microsoft has embedded AI into its Reading Progress tool to allow teachers to create personalized reading passages based on the words or phonics rules that a class or specific student found most challenging.[38] Extending this paradigm to the corporate sphere, companies like Workera offer AI-driven tools that enable businesses to design bespoke learning modules, which are powerful tools for upskilling their workforce in specialized domains like data science and machine learning. Through AI-enabled adaptive learning, professionals can not only acquire relevant skills but also benefit from a curriculum tailored to their specific needs, making the learning process more effective and engaging.

Microsoft