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PROMISE AND PERIL: SUSTAINABILITY & THE RISE OF ARTIFICIAL INTELLIGENCE

Digital Climate Alliance

SUMMARY

Artificial intelligence (AI) could have profound beneficial impacts in a range of areas, including efforts to address climate change and other sustainability issues. At the same time, the growth of AI — and the infrastructure needed to support it — will create additional sustainability challenges. It is imperative to take steps to enhance AI's potential sustainability benefits (its "handprint") and minimize its impacts (its "footprint"). This paper delves into the promise of AI in advancing sustainability solutions across the economy, the potential peril of its footprint, a range of potential solutions for reducing those impacts, and offers recommendations for additional policies and other measures that can help advance AI's potential benefits and minimize its potential impacts.

THE DIGITAL CLIMATE ALLIANCE

Baker Hughes, Black & Veatch, Dell Technologies, Intel, Schneider Electric, and Trane Technologies.

As more and more companies leverage digital technologies to reduce climate impacts, improve energy and water efficiency and resiliency, and drive further innovation across our nation's critical infrastructure, there needs to be a concerted voice coordinating these efforts and advocating for the increased use of digital technologies as solutions to addressing the climate crisis. The Digital Climate Alliance is a coalition of companies developing and utilizing digital technologies to reduce their environmental impacts for themselves and for their customers. The Digital Climate Alliance's goal is to promote digital technologies to enable 21st century solutions, solving climate, water, and energy challenges that impact economic development, business growth, social well-being, and ecosystem health.

ACKNOWLEDGEMENTS

This report was developed by CO2EFFICIENT LLC (COEFFICIENT) for the Digital Climate Alliance with the help and expertise of Dave Grossman from Green Light Consulting. COEFFICIENT is a mission-based strategic consultancy focused on advancing public policy and market solutions in the energy and environmental sectors. Located in Washington, DC, COEFFICIENT is a leader in developing transformational 21st century climate policies that integrate environmental sustainability and corporate governance with digital technology solutions. Learn more at www.co2efficient.com.

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INTRODUCTION

Artificial intelligence (AI) burst into the public consciousness over the past year or two, particularly since the release of ChatGPT in late 2022. AI applications are proliferating, as are debates about policies, ethics, and guardrails. AI could have profound beneficial impacts in a range of areas, including climate change and other sustainability issues. At the same time, the growth of AI itself — and the infrastructure needed to support it — will create additional sustainability challenges. It is imperative to take steps to enhance AI's potential sustainability benefits and minimize its impacts.

WHAT IS AI?

There is not yet a common definition of what AI encompasses, even within the federal government.[1] A recent Executive Order, citing one part of the U.S. Code, defines AI as:

> *A machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments. Artificial intelligence systems use machine- and human-based inputs to perceive real and virtual environments; abstract such perceptions into models through analysis in an automated manner; and use model inference to formulate options for information or action.*[2]

The following definition from the Congressional Research Service provides perhaps a more basic description:

> *AI can generally be thought of as computerized systems that work and react in ways commonly thought to require intelligence, such as the ability to learn, solve problems, and achieve goals under uncertain and varying conditions, with varying levels of autonomy. AI is not one thing; rather, AI systems can encompass a range of methodologies and application areas, such as natural language processing, robotics, and facial recognition.*[3]

The concept of AI has been around since the 1950s,[4] but it has progressed rapidly in the last several years due to the availability of huge datasets, increases in computing power, and the development of improved algorithms and approaches.[5]

Machine learning (ML) is a subset of AI that has underpinned many of the recent AI advancements. Whereas typical computer programs are deterministic, capable only of doing what they were instructed to do by their programmers, ML involves automated systems that use algorithms to analyze massive data sets, learn from their experiences with that data, and produce decisions, predictions, or other outputs based on new, similar data they encounter. The more data that ML systems are trained on, the more they improve their performance in producing outputs when exposed to similar new inputs. ML can help identify patterns in data that humans would miss, at speeds far faster than traditional techniques.[6] The AI developments that have garnered so much public attention recently have been ML models known as generative AI (GenAI), which can turn input prompts into new content, whether language, images, music, computer code, or something else.[7]

BENEFITS AND IMPACTS

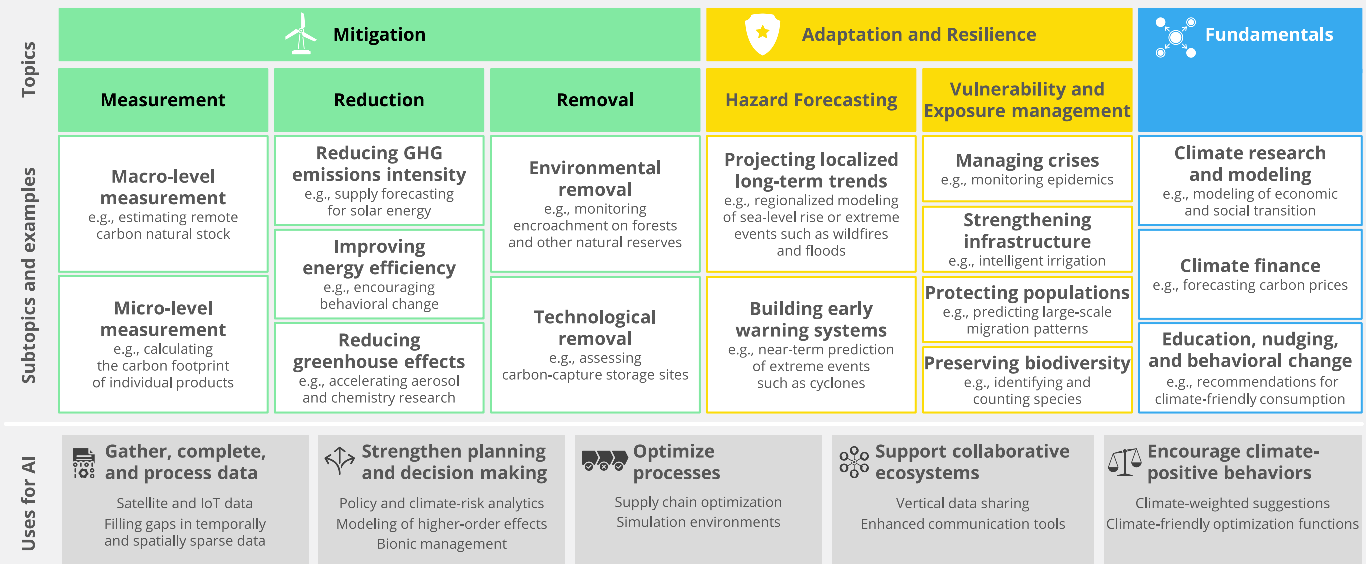
These and other AI tools can provide numerous benefits, including optimizing systems' performance, informing human decisions, and creating useful content.[8] With respect to climate change and sustainability, these tools can help advance solutions in a range of sectors, including improving efficiencies, preventing failures, and identifying new opportunities to achieve sustainability gains. This paper delves into the role that AI can play in advancing sustainability solutions in myriad sectors of the economy, including energy, transportation, buildings, and agriculture. In the lingo of sustainability, this is AI's "handprint" — its role in enabling other industries to reduce their energy, water, and climate footprints.

AI's own footprint, however, must also be considered. AI is not just another run-of-the-mill digital tool, and this paper describes some of the ways that its footprint could be considerable. The paper then reviews a range of potential solutions for reducing AI's sustainability impacts.

The potential benefits and impacts of AI — in the climate and sustainability space and beyond — have garnered significant attention from the federal government. Accordingly, this paper concludes by providing a quick overview of some recent federal actions related to the intersection of AI and climate change and by offering recommendations for policies and other measures that can help advance AI's potential benefits and minimize its potential impacts.

AI'S HANDPRINT: THE ROLE OF AI IN CLIMATE SOLUTIONS

AI could make meaningful contributions to an array of efforts related to climate change, from fundamental science to minimizing the impacts of climate-driven hazards to reducing emissions across sectors. As described more in the figure and the sections below, AI's ability to gather, synthesize, and analyze huge data sets can help a variety of stakeholders in optimizing processes, uncovering solutions, and making more informed, data-driven decisions to address climate change.[9]



Sources: BCG project experience; Climate Change AI, "Tackling Climate Change with Machine Learning"; Global Partnership on AI, "Climate Change and AI: Recommendations for Government Action."
Note: GHG = greenhouse gas; IoT = Internet of Things.

Figure 1: Framework for Using AI in Combating Climate Change
Source: BCG, How AI Can Be a Powerful Tool in the Fight Against Climate Change (2022)

AI SUPPORT FOR FUNDAMENTAL CLIMATE SCIENCE AND HAZARD REDUCTION

Having a good understanding of what is happening with respect to climate change and greenhouse gas emissions is fundamental to tackling the problem, and AI can enhance such understanding. AI is being used to improve the performance of climate models, track global emissions of carbon dioxide and methane, monitor natural carbon sinks, assess the degree to which extreme weather events were driven or worsened by climate change, and more.[10] For example, Climate TRACE (Tracking Real-Time Atmospheric Carbon Emissions) uses AI to track emissions across the globe, training algorithms using data from satellites, other remote sensors, on-the-ground sensors, and other sources to produce a detailed emissions inventory.[11] In parallel to emissions tracking, AI also helps monitor carbon sinks with algorithms trained to measure biomass carbon sequestration in the world's vegetation based on high-resolution satellite imagery.[12]

Similarly, AI is helping to provide earlier warnings of extreme weather events, enhance longer-term hazard projections, analyze optimal infrastructure investments in the face of changing climate-related hazards, and improve disaster response.[13] For example, AI-enabled cameras coupled with models to analyze satellite data, and other measures are increasingly being used to provide early detection of wildfires.[14]

AI IN THE ENERGY SECTOR

AI is already playing a key role in the energy sector; for instance, it can improve power generation, grid operation, demand management, and use of distributed resources. It has begun helping to identify and develop materials that can improve technologies in the energy sector (and beyond). The impacts of AI are considerable, and there is potential for AI to do much more.

With respect to **renewable power generation**, AI can help with siting and sizing large solar and wind projects (e.g., by considering data on weather patterns, topography, grid constraints, and more), maximizing production (e.g., by predicting relevant weather and utilizing satellite data), and predicting and scheduling maintenance to minimize failures. AI can also help manage the construction of renewable energy projects (e.g., optimizing equipment delivery schedules). Beyond wind and solar, AI can be used to improve reservoir modeling, drilling, and production for geothermal energy.[15]

AI can also play a vital role in **grid operation and optimization** by helping network operators understand grid conditions in real time, make more informed decisions, and forecast potential grid disruptions.[16] AI systems can draw huge amounts of data from a range of sources to aid in planning (e.g., which grid equipment to put in which locations), identifying grid infrastructure that needs to be reinforced to deal with extreme weather, monitoring grid performance to improve system efficiency and stability, and providing real-time assessments of the maximum amount of power that transmission lines can carry (i.e., dynamic line rating). AI can support enhanced grid maintenance by facilitating remote inspections of infrastructure, identifying operating parameters that will extend equipment lifetimes, and pinpointing early data trends to predict future failures and arrange for preventive maintenance of equipment.[17] The U.S. Department of Energy (DOE) is funding projects that use AI to support the undergrounding of power lines, which enhances resilience.[18] On the vast, complicated distribution grid, AI can help distribution network operators with fault detection.[19]

BLACK & VEATCH
EMPLOYEE-OWNED

BLACK & VEATCH'S GEOAI FOR UTILITY INFRASTRUCTURE

Black & Veatch has developed a cost-effective way to capture, organize, and analyze data from infrastructure around the world to provide transformative street-level imagery on-demand. Its GeoAI system creates high-resolution 3D images that allow for measurement with centimeter-level accuracy. One potential usage is for performing analysis and measurements of distribution poles, lines, and equipment, to support smart grid and distribution automation design.

See Black & Veatch, "GeoAI: Digitizing the Built Environment", https://www.bv.com/resources/geoai-digitizing-the-built-environment/

As more digitized distributed energy resources, from smart thermostats to electric vehicles (EVs) to battery systems, are added to the grid and produce copious amounts of data, AI will play an important role in **managing energy demand and distributed resources** to better integrate clean energy and enhance grid reliability. A more decentralized grid requires more coordination and flexibility. For instance, AI could help manage the timing and rate of electric vehicle battery charging, improve integration of distributed renewables such as rooftop solar, schedule and optimize energy storage, and aggregate and orchestrate the interaction among distributed resources to create "virtual power plants" that can provide grid services and demand response.[20] Similarly, coupled with advances in smart grid technologies and customer-sited backup systems, AI may be able to help data centers and other buildings be more flexible in how they use electricity; utilizing AI to help unleash flexible demand could unlock numerous benefits, especially in load-constrained regions where market signals can help to prioritize voluntary load shedding at certain times of the day versus having to resort to mandatory curtailments. In addition, AI can help end users, including homes, industries, and data centers, reduce energy demand, such as by leveraging building management systems and using sensor data and computer vision to optimize heating, ventilation, and air conditioning (HVAC) equipment.[21] AI-driven microgrids can also help consumers that both use and generate electricity to optimize when they buy, sell, or store energy.[22]

Many aspects of decarbonization, in the energy sector and beyond, will rely on advanced materials, including solar panels, wind turbine blades, carbon capture catalysts and sorbents, and refrigerants. By processing huge amounts of data (e.g., thousands of articles in the scientific literature) to infer the properties of different materials, AI is already helping to discover, innovate, and produce **potentially promising new materials** that can play key roles in the energy sector, as well as in other sectors.[23] AI can perform such analyses far more quickly than would otherwise be the case — in a matter of weeks, rather than years. AI, for example, has helped discover and synthesize new battery materials.[24] AI can also work backwards, starting with desired properties and proposing new hypothetical material structures that may have them.[25]

AI can have effects on the energy sector in numerous **other ways** as well. For instance, AI can automate inspections of materials in power plants (e.g., welds within nuclear reactors), improve power plant operational efficiency, and predict plasma instabilities in fusion facilities.[26] In oil and gas, AI is helping to scan for and quantify methane leaks, evaluate equipment performance, and model subsurface reservoirs for injecting carbon dioxide.[27]

Schneider Electric

SCHNEIDER ELECTRIC AI FOR DISTRIBUTED RESOURCES

Schneider Electric's EcoStruxure Microgrid Advisor can connect, monitor, and control a facility's Distributed Energy Resources (DER) to optimize performance and enable dynamic control of on-site energy resources and loads. Microgrid Advisor uses a machine learning algorithm that constantly analyzes data from energy generators, electric vehicle charging stations, batteries, heating, ventilation, and air conditioning systems, lighting systems, and more to automatically forecast and optimize how and when to consume, produce, and store energy.

See Schneider Electric, "How different AI solutions support sustainability", https://https://blog.se.com/digital-transformation/artificial-intelligence/2023/10/19/how-different-ai-solutions-support-sustainability/

Microsoft

MICROSOFT USING AI TO DEVELOP NEW MATERIALS

Through its AI for Good Lab, Microsoft Research's AI4Science Lab, and Microsoft Climate Research Initiative (MCRI), Microsoft is using AI to tackle sustainability bottlenecks. For instance, one MCRI project with researchers at MIT and UC Berkeley uses generative ML models to develop new materials and system engineering approaches for carbon capture (e.g., novel metal-organic frameworks).

See Microsoft, "Accelerating Sustainability with AI: A Playbook", https://blogs.microsoft.com/on-the-issues/2023/11/16/accelerating-sustainability-ai-playbook/

AI IN THE TRANSPORTATION SECTOR

In the transportation sector, AI is playing and can play key roles in optimizing travel routes, maximizing the potential of smart infrastructure, promoting lower-emitting public transit, developing improved transportation technologies, managing the growing interface between the electricity and transportation systems, and much more.

AI can promote **route optimization**, and therefore greater fuel efficiency and lower emissions, across a range of travel modes. On the roads, AI-driven route planners and mapping programs draw on both historical and real-time data to identify the most fuel-efficient routes (e.g., with fewer hills or less traffic), whether for individual drivers, commercial trucking fleets, or public transit vehicles.[28] The same is true on the seas, where AI approaches are drawing on ship sensors, weather forecasts, and other data sources to optimize global shipping routes and vessel speeds in ways that reduce fuel consumption and emissions.[29] In the skies, AI has drawn on flight path data, weather data, and satellite imagery to identify flight paths that can minimize the creation of contrails (the white cloud lines sometimes left behind by airplanes) by avoiding atmospheric layers of humidity; such routes may use marginally more fuel, but they substantially reduce the formation of contrails, which account for more than a third of aviation's climate impact.[30]

AI can also enable and maximize the potential of **intelligent transportation systems and smart infrastructure**, which rely on robust collection and analysis of data from various sensors, cameras, and other devices throughout the transportation network. With such data, AI can decrease traffic congestion, inform public transit system planning, and generally better manage road traffic.[31] For example, AI systems can detect traffic-causing situations (e.g., congestion, accidents, road closures) in real time and redirect vehicle flow or suggest alternative travel options accordingly.[32] AI has also been utilized to control traffic signal timing and sequencing to improve real-time traffic flow, reduce idling at red lights, and cut emissions.[33]

Relatedly, AI has the potential to **enable lower-emitting public** transit options. AI can harness a range of data to optimize public transit schedules and routes based on predicted passenger loads and can minimize service failures and delays, which in turn should enhance the appeal of those transit options.[34] AI-driven travel routing platforms can include and encourage lower-emitting transit alternatives.[35] AI can better enable demand-determined transit routes (as opposed to only fixed routes), which can be more responsive to passenger needs.[36] AI-supported traffic signal control can be optimized in real time to facilitate public transit options.[37]

As in the energy sector, AI can help discover, innovate, and produce **potentially promising new materials** that can play key roles in the transportation sector. For example, AI has been used to improve battery designs in electric vehicles, including new cathodes, anodes, and electrolytes that increase EV battery capacity and reduce battery costs.[38] Similarly, AI has played a role in predicting, developing, and optimizing new sustainable biofuels.[39]

The role of AI in the growing **nexus between the energy and transportation sectors** goes well beyond materials. For instance, AI can analyze diverse sources of data to identify optimal locations for public EV charging infrastructure, help manage grid capacity to charge electric vehicles at optimal times, and facilitate bidirectional EV charging, allowing EVs to provide power to buildings or the grid.[40]

Among the more high-profile topics involving AI and the transportation sector is the concept of autonomous vehicles, including cars, taxis, and trucks. Autonomous electric vehicles have the potential to reduce emissions by optimizing trips, reducing congestion, and facilitating the expansion of shared transport.[41]

AI IN THE BUILDINGS SECTOR

AI has emerged as a powerful tool to enable improvements in the buildings sector, including both the performance of existing buildings and the design and construction of new ones.

AI can play a key role in helping existing buildings **optimize energy use** and thus reduce energy-associated emissions. The scope of AI's involvement can range from controls for particular elements within a building (e.g., HVAC) to systems that cover all aspects of energy use across portfolios of buildings. AI, for example, has been used to optimize rooftop air conditioning units at schools that lack broader building energy management systems (BEMS), learning the relationships between classroom temperatures and the demands on rooftop units to achieve significant reductions in energy use.[42] For buildings that do use BEMS, AI can draw on a huge range of data from sensors, energy markets, weather stations, and elsewhere to learn how buildings use energy and automatically adapt and optimize lighting, HVAC, and other systems to save energy.[43] AI-powered BEMS can likewise accurately predict energy demand from buildings, facilitating the integration of on-site renewable energy and participation in demand response programs.[44] More broadly, AI enables owners of portfolios of buildings to draw on satellite data, regulations, building characteristics, and other data to identify site-specific decarbonization opportunities (e.g., efficiency, renewables) at each building, without the need for building-by-building energy audits.[45]

In addition to optimizing the performance of existing buildings, AI can advance decarbonization during the **design and construction** of new buildings. In the design phase, AI can help analyze a project's potential environmental impacts and can optimize building orientation, window sizes, ventilation, building materials, and more to reduce a building's carbon footprint and improve its energy efficiency.[46] With respect to construction, AI is helping contractors choose concrete mixes with lower embodied emissions, helping reduce emissions from cement and steel production, and improving the efficiency of building techniques (e.g., with robots and 3D printing).[47] AI can also help minimize waste by optimizing off-site construction design and materials selection.[48]

TRANE TECHNOLOGIES

TRANE AUTONOMOUS CONTROL

Trane Autonomous Control (powered by BrainBox AI) optimizes Trane systems to reduce buildings' energy consumption and minimize carbon emissions with the power of AI. It identifies and performs system optimization actions 24/7, augmenting existing control systems without requiring additional hardware. The system captures and synthesizes real-time and predictive data (e.g., occupancy levels, weather patterns, system performance information) to optimize efficiency and carbon reduction, reduce operating costs, and support sustainability goals without sacrificing occupant comfort.

See Trane, "Trane Technologies' Latest AI-Enabled Service Offering Propels Building Performance and Accelerates Decarbonization", https://investors.tranetechnologies.com/news-and-events/news-releases/news-release-details/2023/Trane-Technologies-Latest-AI-Enabled-Service-Offering-Propels-Building-Performance-and-Accelerates-Decarbonization/default.aspx

DELL Technologies

DELL SMART BUILDING MANAGEMENT

Desigo CC, a building management software platform created by Siemens Smart Infrastructure and Dell Technologies, can help transform regular buildings into high-performance, energy efficient, smart buildings. Desigo CC pulls information together from different control systems, software, devices, and data sources and consolidates disparate workstreams into a single management system. Desigo CC's AI and data analytics help enhance building performance, optimize efficiency, and enable participation in demand response initiatives that reduce energy use and emissions.

See Dell Technologies, "Desigo CC: Edge solutions streamline smart buildings", https://www.delltechnologies.com/asset/en-us/solutions/industry-solutions/customer-stories-case-studies/dell-desigo-siemens-case-study.pdf

AI IN THE AGRICULTURE SECTOR

The agriculture sector is both a source of emissions (e.g., nitrous oxide from fertilizers, carbon dioxide from energy use) and a sink for emissions (e.g., in soils), and AI is and will continue helping to address climate change on both fronts.

AI is facilitating techniques that can **minimize nutrient and fertilizer applications** (and thus the associated nitrous oxide emissions), as well as water for irrigation. Drawing on a range of data, including sensors, drones, and satellites, AI enables precision agriculture that optimizes agricultural inputs in different portions of fields, reducing the amount of fertilizer, herbicide, and water for irrigation while improving yields.[49] Using similar data, AI can also help **reduce waste from crop loss**, such as by suggesting proactive responses to detected pests or pathogens or to predicted weather conditions, as well as **reduce food loss**, such as by optimizing the timing of harvests to minimize food spoilage.[50] Additionally, AI can utilize real-time data about field conditions, including nutrient levels, organic matter, and soil compaction, to guide practices, inputs, and planting choices that can **maximize carbon sequestration in soils.**[51]

Even out of the fields, AI can play an important role in **reducing waste, energy use, and emissions throughout agricultural supply chains**, including during food transport and storage. AI, for instance, can optimize transportation routes and load planning to reduce the fuel needed to deliver agricultural products.[52]

AI IN OTHER SECTORS

AI's current and potential applications span the economy, and its impact on accelerating efforts to address climate change can extend beyond the energy, transportation, buildings, and agricultural sectors. For example, AI can help decarbonize **industry and manufacturing** by fine-tuning various industrial processes to reduce waste and energy intensity, enabling the use of more recycled feedstocks, and facilitating the use of cleaner energy sources for industrial heat.[53] AI models are helping to identify new domestic sources of **critical minerals**.[54] Across sectors and in the consumer space, AI can help automate and share measurement of emissions tied to products or actions throughout **supply chains**, helping to drive efforts to reduce such emissions.[55] In addition, AI is being used to advance **carbon capture and storage (CCS) and carbon dioxide removal (CDR)** in a range of ways, including evaluating orphan wells for reuse for CCS and enhancing project monitoring and verification for CDR projects.[56]

intel.

INTEL'S SMART AGRICULTURE

Nature Fresh Farms uses Intel's 4th Gen Intel Xeon central processing units for compute to use AI inferencing to help grow 250 acres of crops in greenhouses. The processing is done at the greenhouse or warehouse instead of in the cloud because connectivity is not a given in the areas they are located. Using 25 years of data, Nature Fresh Farms built 32 models that incorporate real-time data such as moisture, light, and humidity to control lighting, ventilation, power management, and other systems. Nature Fresh Farms is seeing benefits of three times the plant yield and, with computer vision with AI, can detect produce of similar age and firmness, ensuring that "like" produce is packaged together, minimizing waste and spoilage.

See "Nature Fresh Farms Presents with Intel at AI Field Day 4", https://techfieldday.com/appearance/nature-fresh-farms-presents-with-intel-at-ai-field-day-4/

Baker Hughes

BAKER HUGHES SUSTAINABILITY AI

Baker Hughes' BHC3 Sustainability offering helps sustainability, plant, and energy managers achieve targets for energy cost, greenhouse gas emissions, water consumption, and waste reduction. It models energy efficiency and emissions at every level of the industrial process from the individual asset to the entire plant carbon footprint. Advanced AI models identify opportunities for energy efficiency, prioritize emission reduction strategies, alert operators to efficiency anomalies, and verify progress against sustainability goals. Utilizing sustainability-focused digital twins, automated AI/ML processes, and industry-specific data models, BHC3 Sustainability can yield reductions of 20-40% in greenhouse gas emissions and 15-30% in water consumption and waste generation.

See Baker Hughes, "BHC3 Sustainability", https://www.bakerhughes.com/bhc3/bhc3-sustainability

AI'S FOOTPRINT: THE ENVIRONMENTAL IMPACTS OF AI

The potential of AI to generate a positive handprint by catalyzing climate change efforts across a range of sectors, as described above, is considerable, but it is also important to consider AI's own climate change footprint and sustainability impacts.

ENERGY USE

The Digital Climate Alliance's March 2023 paper on sustainable data centers pointed out that while data centers consume far more energy than a typical office building, they only accounted for about 1% of global electricity demand in 2021 (not counting use for cryptocurrency mining). Furthermore, the paper noted that energy consumption at data centers across the globe remained basically flat from 2010 to 2020, despite exponential growth in demand for data services.[57] The rapid deployment of AI makes it necessary to revisit those data points. There have been concerns that the energy needed to train and utilize AI systems could lead to significantly higher data center energy usage and significantly higher emissions.

In addition to the embodied energy and emissions associated with manufacturing AI hardware (e.g., servers and purpose-built accelerators), the operational energy footprint of AI comes primarily from two phases: training the AI system on huge amounts of data (the training phase) and deploying the AI to produce outputs based on new inputs (the inference phase).[58]

Training is generally more energy-intensive than inference — inference work is a lighter computational lift — but overall energy use may be greater for inference.[59] Some have estimated that the current relative energy usage between the two phases is roughly 40% for training and 60% for inference, while others have put the split at 20%-80%;[60] the exact ratio will vary by AI system and will depend on factors such as the amount of data used for training, the frequency of retraining, and the end-use involved (i.e., how widespread inferencing is).[61]

Regardless of the precise split between training and inference in any given AI system, the overall energy needs of AI are considerable, though estimates vary. Schneider Electric estimates that AI accounted for about 8% of data center power consumption in 2023 and projects that amount to grow to 15-20% by 2028.[62] Viewed differently, Boston Consulting Group estimates data center electricity consumption was 2.5% of the U.S. total in 2022 and projects that to triple to 7.5% by 2030, with GenAI expected to account for at least 1 percentage point of that increase.[63] Another study analyzing trends in AI energy use found that full-scale adoption of AI to replace every Google search (which is unlikely to happen rapidly if it happens at all) would require the equivalent of the annual electricity consumption of Ireland, and the increased production of AI servers could, by 2027, lead to global AI-related electricity consumption equivalent to the Netherlands, Argentina, or Sweden.[64]

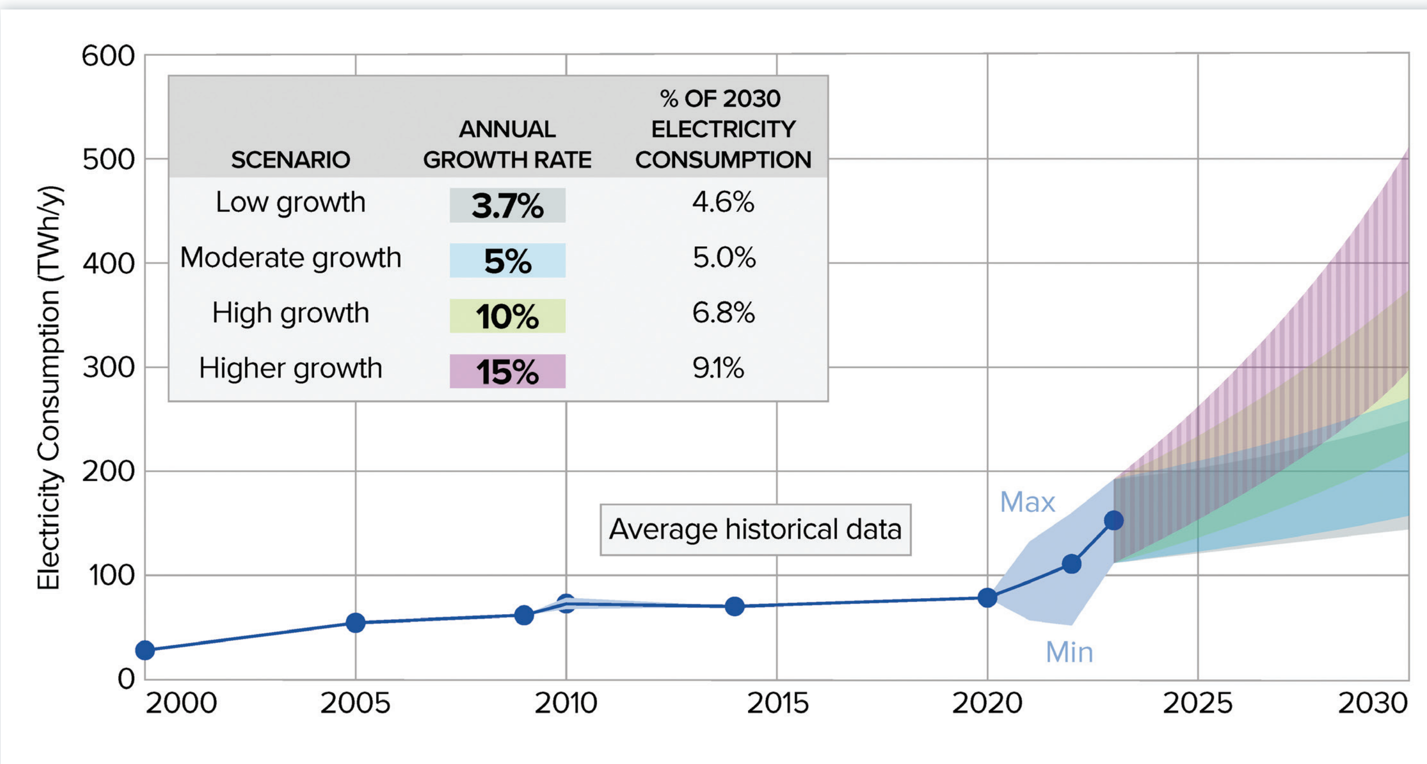


Figure 2: Projected Near-term Data Center Demand

Source: Electric Power Research Institute, *Powering Intelligence: Analyzing Artificial Intelligence and Data Center Energy Consumption,* May 2024, p.17, https://www.epri.com/research/products/3002028905

Long-term projections assessing IT's energy use struggle to reflect the speed that IT changes. Over just the few years that AI computing has taken off, chip manufacturers and server manufacturers have already begun developing the next generation of more efficient AI systems. And liquid cooling is becoming much more mainstream to also improve the efficiency of these AI data centers. It is in everyone's interest to get the most compute for the least amount of energy.

Even with the growth in AI, the greenhouse gas emissions associated with AI remain modest — well under 1% of global emissions.[65] The actual future levels of energy demand and emissions from AI remain unclear, as they are dependent on numerous factors, including the efficiency of future hardware and AI models, demand for AI services, and the amount of clean energy used to power data centers.

WATER USE

The Digital Climate Alliance's March 2023 paper described the billions of gallons of water that data centers consume, both directly (e.g., for cooling) and indirectly (e.g., in producing the electricity that data centers use).[66] AI increases this water demand, as its greater computational needs and thus energy use result in more direct and indirect water usage.

Some leaders in AI have recently reported large increases in water consumption. Microsoft's 2022 Environmental Sustainability Report, for instance, reported a 34% increase in water consumption (more than 420 million gallons) from fiscal year (FY) 2021 to FY 2022, which it described as "proportional to our business growth year-over-year."[67] Google reported a 22% increase in water consumption (about 1 billion gallons) from 2021 to 2022.[68] Outside experts at the University of California, Riverside, and the University of Texas, Arlington, tie much of this growth in water consumption to the companies' AI efforts.[69] The researchers estimate that training a language model such as GPT-3 in Microsoft's U.S. data centers can directly and indirectly consume about 1.4 million gallons of water, including almost 185,000 gallons of on-site water consumption, while GPT-3 consumes about 500 milliliters of water (roughly the amount in a standard 16-ounce bottle) for every 10-50 responses it gives to new inputs.[70] If estimates of AI's growing near-future energy usage are correct, then the researchers project that by 2027, direct and indirect global water consumption for AI could be more than 100-150 billion gallons.[71]

SOLUTIONS TO REDUCE THE IMPACTS OF AI

There are solutions that can help reduce the sustainability impacts of AI. Many of these were reviewed in the Digital Climate Alliance's March 2023 paper on sustainable data centers, including energy efficiency optimization, clean energy, water conservation and stewardship, reuse of waste heat, and circular economy efforts. These remain important, and some of these are reviewed briefly below. Given the increased energy demands of AI (in conjunction with electrification of other sectors), additional solutions for data centers will also be needed.

ENERGY AND WATER EFFICIENCY

Just as data centers' energy efficiency improvements allowed their energy consumption to remain basically flat for a decade despite huge increases in data center demand, the energy efficiency of AI hardware and software similarly continue to improve. Significant energy efficiency improvements are still available at many data centers, and computational equipment and ML models both continue to improve in efficiency and performance.[72] Shifting processing loads to times and locations that have less carbon-intensive power can likewise help reduce emissions.

There are other opportunities for improving efficiency as well. For instance, waste heat captured by various types of cooling systems (particularly liquid cooling designs) can be reused by the data center, reducing the need for additional energy inputs. (If the captured waste heat is used by and reduces the energy needs of others nearby, such as by connecting to district heating systems,[73] that would be a different sort of data center handprint — one based on the physical infrastructure as opposed to data services.) Modular data centers, which are units built with prefabricated, preconfigured equipment, can also help with energy efficiency and other sustainability goals, as they can utilize the newest and most efficient technologies, little (or no) concrete, fewer building components, and smaller footprints.[74] In addition, digital twins — which involve creating virtual replicas of physical assets (e.g., servers, cooling systems) — can leverage real-time data and predictive analytics to optimize power use, cooling efficiency, equipment placement, and other aspects of data center operation, potentially leading to energy savings of up to 30%.[75]

Likewise, data centers can improve energy efficiency by improving compute efficiency, which may be enabled by the introduction of new metrics that will measure specifically how much energy is being used by information technology equipment for computing; several organizations are working on developing such metrics. While there are already numerous metrics that help track data center sustainability,[76] once the energy efficiency of compute processing for AI can be measured, it is more likely that manufacturers of equipment will be able to make further efficiency improvements, which could help reduce the energy required for processing AI in the future.

INTEL'S PROCESSORS WITH BUILT-IN AI ACCELERATORS

4th and 5th Gen Intel Xeon processors include built-in AI accelerators that provide improvements in performance and watt/power savings. Recently, Siemens Healthineers developed an AI-enabled solution for auto-contouring organs for radiation therapy. By employing 4th Gen Intel Xeon processors with built-in AI accelerators, Siemens was able to enable AI auto-contouring 35 times faster while reducing energy consumption by 20%.

See Intel, "Siemens Healthineers Boosts Image Processing", https://www.intel.com/content/www/us/en/customer-spotlight/stories/siemens-healthineers-customer-story.html

GOOGLE'S BEST PRACTICES FOR ENERGY SAVINGS

Google found that a combination of efficient ML model architectures, optimized ML processors, computing in the cloud rather than on-premise, and cloud computing in locations with the cleanest energy resulted in reductions in energy usage associated with AI up to 100x and reductions in greenhouse gas emissions up to 1000x. If ML communities follow these best practices, Google predicts the carbon footprint of ML training will plateau and then shrink this decade.

See Patterson et al., "The Carbon Footprint of Machine Learning Training Will Plateau, Then Shrink", https://doi.org/10.1109/MC.2022.3148714 *(accessed at* https://arxiv.org/ftp/arxiv/papers/2204/2204.05149.pdf*)*

It is, however, also possible that improved efficiency could trigger a rebound effect, leading to even more demand for and use of AI and thus more total energy usage; improved efficiency could also enable older unused processors to be repurposed for AI, which could further increase energy consumption. In addition to improving efficiency, therefore, some have also called for more focus on using AI only where it is actually useful (i.e., more efficient and purposeful deployment).[77]

Continued efforts to improve water efficiency are likewise essential. Similar to efforts to do AI computing in locations with the cleanest energy, decisions about when and where to train and deploy AI models can have significant impacts on water usage (and energy consumption), such as by choosing locations where cooling needs are less intensive.[78] Improved disclosure of water usage (not just carbon emissions) in AI model descriptions would provide a good basis for tracking progress.[79]

Liquid cooling represents an approach that can reduce both energy consumption and water usage.[80] Because liquid has higher thermal conductivity and heat-absorbing capacity than air, liquid cooling systems remove heat from computing equipment more efficiently, require less energy to operate, and can better enable reuse of waste heat compared to typical air-cooling systems.[81] Immersion cooling, in which servers are kept completely immersed in a liquid that absorbs their heat, takes greatest advantage of liquid's heat-absorbing capabilities and is the most energy-efficient form of liquid cooling.[82] As noted in the Digital Climate Alliance's 2023 paper, immersion cooling can reduce data center water consumption by more than 90% while also reducing energy use.[83]

BROADER CLEAN GENERATION NEEDS

AI is just one aspect of changes in technology and the economy that are spurring a new increase in electricity demand, and the solutions to that challenge are far broader than can be addressed by data centers alone. Policy will be vital, as discussed in the next section, but so too will the emergence of other technologies to provide enough clean power to meet growing electricity demand without increasing greenhouse gas emissions. Even when targeted specifically at data centers, these solutions, if they can scale, can also help provide broader support to a range of sectors and to the grid.

For example, in addition to current clean energy options (e.g., wind, solar, hydropower) that are already cheap and widely available, other renewable options, such as enhanced geothermal, could play a key role in providing clean power for data centers (and other needs).[84] Geothermal is also being used to provide cooling for data centers.[85] Other non-emitting energy sources, such as small modular nuclear reactors (SMRs), could also theoretically help meet the needs of data centers and the broader grid, if they emerge as a viable commercial option.[86] Likewise, clean hydrogen, if it scales and becomes more affordable and widely available, could be used in fuel cells to replace diesel fuel for data centers' emergency backup power.[87] The range of zero-emitting generation and storage options can also be combined into a microgrid, which can provide high levels of reliability, accelerate decarbonization, and provide support to nearby communities.[88]

POLICY ACTIONS AND NEEDS

Policy will play a central role in guiding the future of AI, its ability to help advance sustainability, and efforts to minimize its sustainability footprint.

RECENT ACTIONS IN WASHINGTON, DC

As AI continues to grow, Congress and the White House have been paying attention. Congress has passed a range of laws addressing AI in recent years, with the most expansive being the National Artificial Intelligence Initiative (NAII) Act of 2020.[89] Among many other things, the NAII Act codified the establishment of an American AI Initiative, established a National Artificial Intelligence Initiative Office and an interagency committee at the White House Office of Science and Technology Policy to support and coordinate federal AI activities, and directed AI activities at a range of agencies, including DOE.[90] The CHIPS and Science Act also included several provisions on AI, including directing DOE and others to support research and development (R&D) activities and technical standards.[91]

According to the Congressional Research Service, at least 40 bills related to AI or ML have been introduced in the 118th Congress as of June 2023, with none enacted. These bills addressed topics such as oversight of the government's approach to AI, training federal employees on AI, export controls on AI, and support for use of AI in various contexts.[92] Congress has also been holding hearings about AI's role in key sectors. For example, in October 2023, the House Energy and Commerce Committee held a hearing that examined the role AI can play in America's energy sector, with witnesses testifying about how AI could optimize grid reliability, help the oil and gas industry, improve nuclear reactor performance, and help reduce emissions. Committee members raised concerns about the national security implications and resource intensity of AI.[93] In November 2023, the Senate Agriculture Committee held a hearing to examine the benefits and risks of AI in food production, processing, and related areas, with witnesses testifying about the benefits of new technologies (e.g., increased crop yields, reduced waste) and the importance of providing clear benefits to growers. Committee members recognized the potential for AI to help advance the agriculture sector but expressed concerns about risks related to farm data protection, technology affordability, and unforeseen consequences.[94]

Complementing committee hearings, the Senate also held a series of AI Insight Forums, findings from which formed the basis of the Bipartisan Senate AI Working Group's roadmap for AI policy, released in May 2024.[95] The roadmap lays out suggested policy priorities for bipartisan consideration in the Senate, including increasing funding for innovation, mitigating potential negative impacts and risks, and establishing a strong federal data privacy framework.

In the Executive Branch, in November 2023, the White House issued Executive Order 14110, on the Safe, Secure, and Trustworthy Development and Use of Artificial Intelligence, which set federal priorities on AI by spelling out agency roles, creating a centralized oversight body at the White House, and emphasizing privacy and equity protections. Among many other things, Executive Order 14110 directed DOE, in consultation with other relevant offices and agencies, to take a range of steps "to support the goal of strengthening our Nation's resilience against climate change impacts and building an equitable clean energy economy for the future." These steps include issuing a report on AI's potential to enhance the grid and help provide clean power, collaborating with the private sector and academia to support development of AI tools to mitigate climate risks, and expanding partnerships to help support AI applications that can "increase community preparedness for climate-related risks, enable clean-energy deployment (including addressing delays in permitting reviews), and enhance grid reliability and resilience."[96]

Responding to the Executive Order, DOE launched the Office of Critical and Emerging Technology in December 2023 to leverage the Agency's capabilities to accelerate progress on AI, biotechnology, quantum computing, and semiconductors, realize their potential, and help solve critical science, energy, and security challenges.[97] In April 2024, as part of a broader suite of AI-related announcements, DOE issued its AI for Energy report describing how AI can be immediately deployed to optimize grid management and to support a range of other clean energy applications, while emphasizing the need to ensure these AI uses do not create new risks for the grid, other infrastructure, or society.[98] Other DOE actions in April 2024 included a report from the national labs on long-term advanced research directions in AI for energy, a website of DOE-developed AI tools and models, and more.[99]

POLICY RECOMMENDATIONS

The recent action in Washington, DC has been important, but more is needed. As AI demand continues to grow, the federal government should develop policies to minimize AI's footprint and amplify its handprint. Policies are needed to enhance the ability of AI to reduce greenhouse gas emissions, foster the sustainability of the data centers that support AI development and deployment, and ensure the grid can meet increasing demand. Additionally, it is crucial that policymakers understand that data centers built for large AI models are different from past data centers, which will have to inform the actions the federal government takes.

Federal actions and policies should include the following:

Understanding and Mitigating AI's Footprint

1. **Establish a distinct category for data centers in the U.S. Energy Information Administration's Commercial Buildings**

Energy Consumption Survey. In the 2018 survey, data centers were placed in the "other" category, which also includes crematoriums, public restrooms, and many other building types. As AI booms and data centers proliferate, it is important to gather more granular data on these facilities. The new data centers category should have various subcategories of data centers, distinguish cryptocurrency mining from High-Performance Computing (HPC) facilities, and include energy, water, and workload statistics.

2. **Direct Lawrence Berkeley National Laboratory (LBNL) to update its data center efficiency report every two years.** In the past, Congress has commissioned LBNL to produce these reports on an ad hoc basis.

3. **Create a dedicated "policy home" within the Executive Branch to develop and implement a coordinated policy approach for AI infrastructure governance across federal agencies.** As noted above, federal agencies, including DOE, the General Services Administration, and the White House Office of Science and Technology Policy have taken a range of actions related to AI, but there is currently no coordinated federal approach to data center efficiency and use. As the demand for data centers continues to grow, it is crucial to prioritize efficient and sustainable operations.

4. **Include sustainability metrics in implementation of the Federal Data Center Enhancement Act of 2023, specifically through enhanced internal management and increased reliance on third-party data center providers.** Federal data center management should begin with cost management through Chief Financial Officer-level responsibility of how federal data centers are run, sited, and maintained. Federal agencies should also enable as-a-service models for the public sector by allowing cloud use (which can frequently be provided at a lower carbon intensity than is achievable within government data centers), educating on carbon-aware computing (which enables data centers to shift flexible tasks to different times of the day or different locations to maximize the use of carbon-free electricity), and including energy efficiency for data centers and cloud services in national digital policy initiatives.

5. **Encourage the adoption of liquid cooling solutions in both new and existing data centers deploying high performance computing applications/AI infrastructure.** The federal government should promote best practices for liquid cooling to reduce energy consumption and water usage as well as to minimize harm and risk to the natural environment, workers, and the public. This includes promoting the elimination of per- and poly-fluoroalkyl substances (PFAS) — which are persistent, bio-accumulative, and toxic — in liquid cooling applications for the information and communications technology equipment industry.

6. **Encourage the development and adoption of waste heat recovery systems within data centers.** The technology for reusing heat from data centers is robust and offers significant opportunities for both energy savings and environmental benefits. There is also a need to incentivize retrofitting existing data centers to accelerate the adoption of such systems. In addition, to bolster the ability of data centers to help reduce others' energy needs, the federal government should facilitate partnerships between data centers and local governments or utilities to use the recovered heat for public buildings or district heating systems.

7. **Urge the U.S. Department of Energy to develop a research agenda for further research and development needs to reduce data centers' sustainability footprint.** This should include research related to liquid cooling, materials science, and next-generation clean firm power. For example, it is important to promote R&D on data center power and cooling efficiency.

Growing AI's Handprint

8. **Promote measures to encourage AI literacy and skills development in the public sector.** To ensure policy and regulatory frameworks foster AI-enabled climate action, it is important for policymakers, civil servants, and others to understand AI and its potential to help support a range of climate solutions across sectors.[100] Participation in initiatives such as Government AI Campus, an online career development initiative that prepares government staff in the age of AI (created by Google and the Rockefeller Foundation), should be encouraged.[101]

9. **Direct the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), and state public utility commissions to evaluate barriers to flexible demand that exist in wholesale and retail markets.** As noted earlier, AI can help data centers and other buildings be more flexible in how they use electricity, boosting grid reliability by better enabling grid operators to rely more on voluntary demand adjustments and less on broader (involuntary) outages. Unleashing demand flexibility, enabled by AI's abilities to match loads in times of constraint, will require reforms to market designs and standards. The new Federal and State Current Issues Collaborative — which FERC created at its March 2024 open meeting to discuss a variety of issues related to the grid[102] — should carefully consider how to adjust wholesale and retail market designs to boost flexibility on the grid. Likewise, FERC and NERC should initiate a review of necessary changes to reliability standards to ensure they help promote flexible demand.[103]

10. **Accelerate the deployment and utilization of dynamic line rating and other grid enhancing technologies.** While the U.S. needs to build more transmission lines to meet expected load growth demand (from AI and other sources), it is imperative to also explore opportunities to enhance the existing systems. FERC and regional transmission planning authorities should prioritize the use of AI to identify areas of existing transmission systems where grid enhancing technologies or line reconductoring can add more capacity and save money for customers.

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