# Artificial Intelligence

The term artificial intelligence (AI) describes systems or tools capable of executing tasks that are usually associated with human intelligence, such as decision making, learning, and problem-solving across different environments.[1] AI's foundational research was conducted by Marvin Minsky, John McCarthy, and Alan Turing.[1] AI models have passed the famous Turing test as early as 1966 by persuading 30% of investigators that they were communicating with a human.[1,2,3]

Terms Associated with Artificial Intelligence

- **Machine Learning (ML)** is a subfield of AI where the system can create models based on data (i.e., learn).[1]

- **Deep learning** is used to describe a family of ML models that typically take the form of biologically inspired neural networks.[1]

- **Generative AI (GenAI)** models can create new data such as text, images, and videos, building on data that they have been trained on.[4]

- **Large language models (LLMs)**, such as ChatGPT, can comprehend and generate natural language to accomplish diverse tasks such as text classification, sentiment analysis, and conversation.[5]
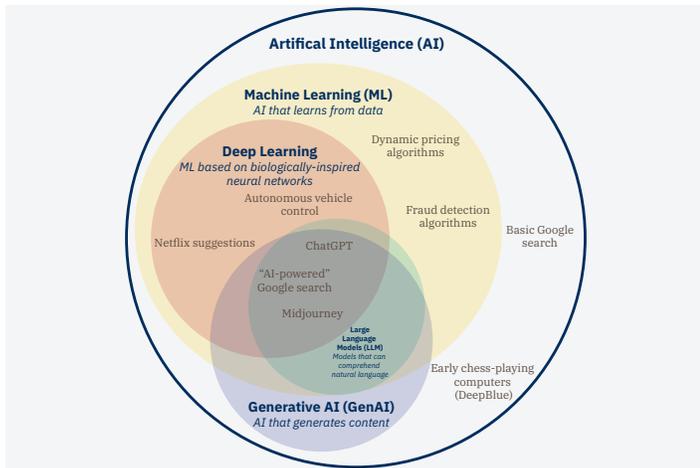
AI innovation has accelerated rapidly, with global AI patents surging 63% from 2021 to 2022 and increasing more than 31-fold since 2010.[6] AI has significant potential to positively affect sustainability, but with the recent introduction of GenAI, the energy demands and GHG consequences of training and running AI models have grown dramatically, creating a sustainability trade-off.[7,8,9]

Patterns of Use

- In 2022, 27% of Americans reported interacting with AI multiple times a day, with 28% engaging with AI once a day, and 44% not considering themselves regular AI users.[10] Only 17% of Americans believe that AI will have a positive effect on the country, while nearly half are unsure or think the effect will be equally positive and negative.[11]

- In 2023, only 6.5% of American businesses planned to implement or had already implemented AI.[12] After the introduction of GenAI, the percentage of organizations using AI grew 72% in 2024, with more than ⅔ of commercial respondents (outside of Central and South America) reporting AI adoption in their organizations.[13] Companies are integrating AI into more areas of their operations, with half of respondents indicating use in at least two business functions—an increase from less than a third in 2023.[13]

- AI is having a significant impact on healthcare by enhancing diagnostics, patient interaction, drug development, and medical reasoning.[14,15] Studies have shown that AI can match or surpass human experts in image-based diagnoses.[14] In 2022, researchers had modeled just 0.1% of known proteins critical to drug development, when an AI model predicted structures for over 200 million proteins, accelerating the discovery by a factor of 45,000.[16]

Energy Use

- Research suggests that over half of recent data center load growth may be attributed to AI and specifically ML.[17] However, AI's energy use currently represents only a small portion of technology sector demand and an estimated 0.01% of global annual GHG emissions in 2024.[8]

Share of AI in Data Center Energy Consumption (estimated from IEA and LBNL data)[18,19,20]
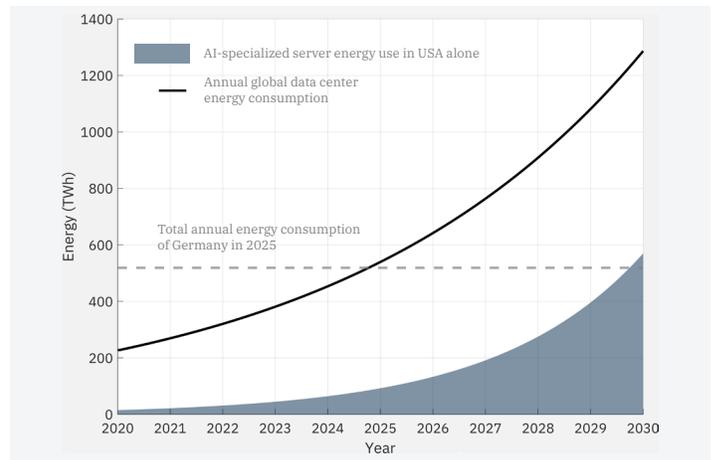
- Hyperscale data centers that have much greater processing power than traditional data centers are often used for commercial deployment of AI models due to their high computational cost.[21] These data centers require immense energy resources, raising concerns about AI impacts on power costs and grid reliability.[22,23]

- Generative AI requires substantial computing power, using significantly more energy than task-specific software—up to 33 times more per task, particularly in areas like text classification (e.g., email spam filtering) and question answering (domain-specific chatbots).[24] For example, each ChatGPT request is estimated to use 2.9 Wh of electricity, ten times the 0.3 Wh used for a standard Google search.[25]

- The energy consumed by a given ML model depends on the model size, which is represented by the number of parameters that are fitted during the training process.[26] The number of parameters can reach up to trillions for the most complex models (such as GPT-4).[26]

Energy Use of LLMs (Wh/1000 Inferences)[25,27,28,29]
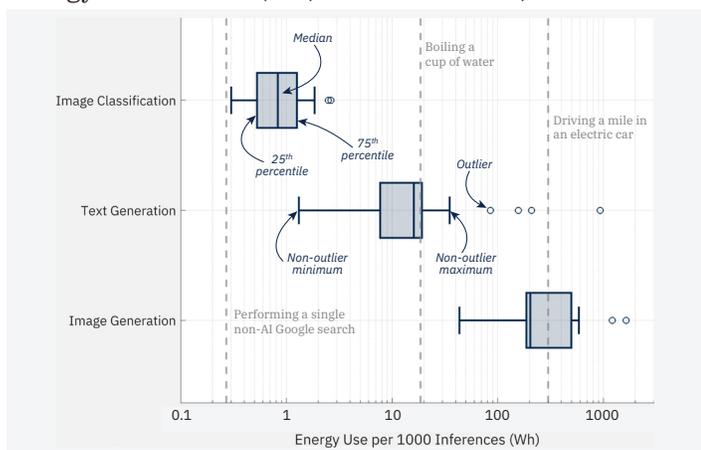
- While inference—the process of generating responses—uses energy, training ML models remains orders of magnitude more energy- and carbon-intensive.[24] Research indicates that a single training run can require the equivalent energy of hundreds of millions of inferences.[24] However, this one-time cost is eclipsed by the ongoing inference cost from widespread deployment of ML models.[24,26]

- AI's environmental impact may be geographically disproportionate.[30] Google's data center in Finland operated on 97% renewable energy in 2022, but its data centers in Asia used 4–18% carbon-free energy.[30]

AI-Driven Sustainability

- By processing large datasets, such as weather and energy use patterns, AI can predict energy production and demand with high accuracy.[31,32] The IEA estimates that AI could bring annual savings of $110B by 2035 through avoided fuels and lower operating costs.[16] AI-driven power management of telecommunication networks has been claimed to cut energy costs and carbon emissions by as much as 50%.[32]

- BCG reports that implementing ML-driven controls and predictive maintenance has on average reduced their manufacturing and oil and gas industry clients' emissions by 5% to 10%.[33]

- ML can also improve energy use estimation for large communities and was, for example, used to evaluate the energy use of New York City's 1.1 million buildings and create a building efficiency ranking.[34,35,36] AI-enabled HVAC and building energy management systems have led to electricity savings of up to 10% in communities in Sweden and India.[16,37,38] The IEA predicts that, by 2035, AI solutions could save more than 100 TWh/year in non-residential buildings and between 30-40 TWh/year in residential buildings.[16]

- In agriculture, AI can be used for smart irrigation control (optimization of water usage), crop disease detection, and automation of afforestation.[17,36]

- AI can improve weather and wildfire predictions.[31,39] The GenCast machine learning model has demonstrated significantly higher accuracy in severe weather forecasting compared to traditional ensemble models.[31] GenCast also enhances wind power predictions by being up to 20% more accurate for short-term forecasts than non-AI methods.[31]

- In transportation, ML has been successfully used to increase accuracy and decrease computational time when predicting emissions from complex traffic patterns.[40] AI-driven route optimization has been shown to decrease fuel consumption and emissions by up to 15%.[16] AI is also used for predictive maintenance of commercial vehicles to increase fuel efficiency and decrease service costs.[16]

- AI has the potential to significantly accelerate the discovery of more efficient photovoltaic materials for use in solar panels, as well as carbon-capture materials and electric vehicle battery materials.[16,41]

Sustainable AI

- Some experts argue that the term "sustainable AI" has been overused and that an application of AI cannot be considered fully "sustainable" if the model is not sustainably implemented (i.e., running on renewable energy).[9]

- Limited regulatory oversight of AI has enabled unrestrained AI implementation without adequate environmental or societal accountability.[7] In some cases, perceived benefits of AI might be used to justify limited regulation or delay the adoption of more sustainable alternatives.[7]

- There are many applications of AI that can be impactful, but there are also areas where it is either ineffective or even counterproductive.[7] AI is widely used to accelerate fossil fuel exploration and extraction, and some models consume substantial energy during training and operation, contributing to emissions.[7,36]

- Advancements in both commercial and open-source AI models have introduced techniques to enhance energy efficiency while reducing computational and memory demands without sacrificing performance.[17] However, these increases in efficiency do not necessarily reduce total AI energy use due to rebound effects and the Jevons paradox (increases in efficiency lead to reduced costs, which in turn lead to increased use).[7,8]

- While tools for measurement of AI model energy use have been developed and are readily available,[27] sharing of these energy data remains one of the biggest bottlenecks for accurate estimation and prediction of AI effects on sustainability.[7]