The Journal of High School Research

Climate and Environmental Impacts of Artificial Intelligence

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Submitted: 07 December 2024 **Accepted:** 07 December 2024 **Publication date:** 07 December 2024

ISSN: 3066-2664: **DOI: 10.70671/2ft99c50**

Abstract: The adverse effects of climate change on our environment and life have been of significant concern, and this concern has become more significant because of recent extreme hurricanes and flooding in various parts of the world. Artificial Intelligence (AI) based technologies are being adopted across all aspects of our life. One of the most frequent arguments in support of AI is that AI-based tools can achieve significant improvements in efficiency, which could translate into much better economic returns while optimizing the use of resources. However, the environmental and carbon footprints of data centers training and facilitating the use of AI tools such as ChatGPT is enormous and is increasing rapidly with explosive growth in AI-related tools. This paper presents a detailed discussion on both beneficial and adverse aspects of AI with respect to its impacts on the climate and the environment based on a critical review of several available studies.

Author keywords: Climate Change; Artificial Intelligence; deep learning; Environmental Impact; Carbon Footprint; Environmental Footprint; Machine learning; deep learning

Introduction

Recent progress in artificial intelligence has been marked by significant advancements across multiple domains, with notable breakthroughs in generative AI, natural language processing, and reinforcement learning. Models like OpenAI's GPT-4 have demonstrated a profound ability to understand and generate human-like text. AI's applications in areas such as healthcare have expanded the ability to analyze vast health datasets beyond human capabilities.[1] Similarly, AI-driven systems in robotics are becoming more adept at real-time decision-making, allowing for greater autonomy in complex environments like autonomous vehicles and industrial automation. Advancements in multimodal AI to integrate text, images, and video drive innovation in areas ranging from content creation to personalized education.[2]

Climate change is driving a range of serious and interconnected environmental, economic, and social challenges with profound effects on ecosystems and human livelihoods. According to the Intergovernmental Panel on Climate Change (IPCC), rising global temperatures have already led to more frequent and intense extreme weather events, including heatwaves, floods, and storms, which disproportionately impact vulnerable populations.[3] Studies have shown that changes in precipitation patterns and the melting of glaciers are altering water availability, jeopardizing food security, and displacing millions of people due to sea level rise.[4] Additionally, biodiversity loss is accelerating as various ecosystems face adverse stress from warming temperatures and habitat destruction, threatening species survival and their ecological services.[5] The economic costs of these impacts are expected to be substantial, with some estimates suggesting that unchecked climate change could reduce global GDP by up to 10% by the end of the century.[6] As the urgency of addressing climate change deepens, global efforts toward mitigation and adaptation are increasingly recognized as critical for avoiding catastrophic consequences.

Recent developments in artificial intelligence offer a unique opportunity to address many challenges associated with climate change effects.[7] However, there are also significant concerns about the adversarial impacts of AI on our natural environment, primarily because of the large amounts of energy and water consumed by the data centers hosting AI tools. As per an estimate by Choo,[8] data centers for AI account for 2.5 to 3.7 percent of global greenhouse gas emissions, exceeding even those of the aviation industry. The possibility of AI in all modes of our activities has the potential to reduce up to 60% of energy-related CO_2 emissions in the coming years.[9] However, the pace of development of AI-related tools and data centers can undermine this target severely because of hurdles with the effective implementation of AI-based tools in time. As a comparative analysis by Shumskaia,[9] CO_2 emissions during a round-trip flight from New York to San Francisco are estimated to be around 163 kg/hour. Compared to this, the estimated carbon emission for training one model with neural architecture is around 94 kg/hour. A comparative study by Strubell[10] shows that the percentage of renewal energy by Amazon-AWS, Google, and Microsoft is 15%, 56%, and 32%, whereas their usage of coal energy is 30%, 15%, and 31%, respectively. With recent competition among top cloud computer providers to make platforms such as ChatGPT freely available to the public

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and incorporate AI in all aspects of most of the commonly used software, CO_2 emission by data centers supporting AI-related training and search tasks is probably already much more extensive than other significant sources of CO_2 emissions. This aspect of CO_2 emissions is currently not well understood because of the nondisclosure of emissions by top AI tools companies in a transparent manner.

Besides the carbon footprint, the water footprint of AI also remains equally concerning. For example, training GPT-3 in Microsoft's state-of-the-art U.S. data centers can directly evaporate 700,000 liters of clean freshwater.[11] Globally, AI demand may be accountable for 4.2 to 6.6 billion cubic meters of water withdrawal in 2027, which will be more than the total annual water withdrawal of 4 to 6 Denmark or half of the United Kingdom.[11]

Despite these concerns, according to a report by the Pwc,[12] AI is expected to transform both productivity and GDP, and 45% of total economic gains by 2030 is expected to come from product enhancements, stimulating consumer demand fueled by greater product variety, increased personalization, attractiveness and affordability over time. Technologies related to AI are expected to value more than $16 trillion by 2030, with the greatest boost of 26% and 14.5% in China and North America, respectively.

Potential Beneficial Impacts of AI on Power Management

Although there are severe concerns about enormous carbon footprint of AI-related tools because of very power demand in data centers, AI-related tools also have a significant potential to reduce emissions by optimizing use of power in all aspects of human activities. Some areas where potential benefits in optimizing and reducing power derived from fossil fuels are listed below.

- **Smart Grids, Energy Efficiency, and Optimization of Usage:** AI has the potential to facilitate improvement in energy efficiency and optimization of energy usage through the development of smart grids, energy demand and usage forecasting, and integration with renewal energy sources. AI-powered smart grids can optimize energy distribution, reduce energy losses, and balance supply and demand. By predicting power consumption patterns in real-time, AI can help utilities manage energy resources more effectively and reduce waste. This can be done by predicting peak demand periods and automatically adjusting consumption or price signals to reduce strain on the power supply. Various AI techniques, such as machine learning and predictive analytics, can forecast electricity demand in real-time and adjust consumption accordingly.[13,14]
- **Energy Storage, Forecasting, and Grid Integration:** AI can improve the management of energy storage systems, allowing renewable energy sources like solar or wind to be better integrated into the grid by optimizing when and how stored energy is used. AI can also optimize the charging and discharging processes of energy storage systems, predicting energy demand and generation patterns and improving the overall efficiency and reliability of the power grid. With the increasing use of renewable energy sources (RES) such as solar power in homes, there are significant uncertainties for cloud-based energy storage management with renewable energy integration. AI-based technologies can provide an estimation of day-ahead energy needs so that energy generators using fossil fuel-based plants can optimize resources to minimize emissions of CO_2.[15]
- **Smart Appliances and IoT:** AI is being used in smart homes and appliances that can reduce energy consumption by optimizing heating, cooling, lighting, and appliance use based on real-time needs and patterns, thus lowering overall electricity demand. In the current state of technology, AI algorithms can enable smart appliances to dynamically adjust their operations based on real-time data, such as predicting and responding to users' behaviors, preferences, and environmental conditions. AI techniques are already being applied in smart heating, ventilation, and air conditioning (HVAC) systems, lighting, and appliances to reduce energy consumption by aligning usage with actual needs.
- **Energy and Carbon Emissions of Commercial Buildings:** Office buildings are the most common type and account for the highest electricity consumption (20%) among all commercial buildings. The energy consumption in office buildings is dominated by medium office buildings, accounting for 70% of the total. A study by Ding et al.[16] has shown that adopting artificial intelligence could reduce energy consumption and carbon emissions by approximately 8% to 19% in 2050. Combined with energy policy and low-carbon power generation, it could approximately minimize energy consumption by 40% and carbon emissions by 90% compared to business-as-usual scenarios in 2050.

Potential Beneficial Impacts of AI on Water Management

Water is used in all aspects of AI, including chip manufacturing. However, even excluding water usage due to supply chains (water for chip manufacturing), AI data centers use an enormous amount of water for both on-site cooling and off-site electricity generation. Water consumption of global AI may exceed 0.38–0.60 billion cubic meters, i.e., roughly evaporating the annual water *withdrawal* of half of Denmark or 2.5–3.5 Liberia. Therefore, AI models can, and must, take social responsibility and lead by example in the collective efforts to combat the global water scarcity challenge by cutting their own water footprint.[11] However, AI models can also contribute to improved water footprint by enhancing water efficiency in other aspects of our lives, such as irrigation, water distribution, monitoring, and treatment.

- **Water Conservation and Efficiency Through Smart Irrigation:** Artificial intelligence (AI), along with machine learning and data analytics, can be used to optimize irrigation by integrating real-time data on weather patterns, soil moisture levels, and crop water requirements. Smart irrigation systems using AI can reduce water wastage by providing precise irrigation schedules and quantities, leading to more efficient water use in agriculture. The outcome is not only water conservation but also improved crop yield.[17,18]
- **Water Pipe Leak Detection:** Artificial intelligence (AI) can be used for detecting and localizing leaks in water distribution systems, such as pipelines, to minimize water loss. In this type of work, machine learning, neural networks, and data analytics process sensor data from pipeline monitoring systems to identify abnormal patterns indicative of leaks, which results in faster response times for repairs and reduced water wastage in urban and industrial water systems.[19]
- **Water Usage Monitoring:** AI tools can be used in water usage monitoring in both industries and households by using smart sensors, AI algorithms, and data analytics to track water consumption patterns in real-time, allowing consumers and businesses to adjust their usage and reduce waste. AI-driven systems can identify inefficiencies, detect leaks, and provide insights that promote responsible water consumption, contributing to better water management in smart cities.
- **Predictive Maintenance During Water Quality and Treatment:** AI models can predict maintenance needs in water treatment plants and wastewater facilities, preventing breakdowns and ensuring consistent water quality. AI models can analyze historical data, sensor readings, and operational parameters to predict equipment failures before they occur. This predictive capability helps to reduce unexpected breakdowns, lower maintenance costs, and ensure consistent water quality by enabling timely interventions and optimizing maintenance schedules.
- **Water Quality Monitoring:** AI can analyze data from sensors to detect contaminants and pollutants in water, such as heavy metals, bacteria, and other harmful substances, enabling more rapid responses to water quality issues and reducing risks to health. By identifying risks to public health and improving water safety, AI-driven monitoring systems are shown to enhance water quality management.
- **Climate and Hydrological Predictions of Drought:** AI can be used for drought prediction and forecasting by analyzing meteorological, hydrological, and environmental data through machine/deep learning. This can result in improving the accuracy and lead time of drought predictions, enabling more effective water management practices and policy decisions. By predicting droughts in advance, governments and organizations can allocate resources more efficiently and implement strategies to mitigate the impacts of water scarcity.
- **Flood Prediction:** AI can be used in flood prediction systems by analyzing weather patterns, hydrological data, and other environmental variables to forecast floods through machine learning and other AI techniques. This can result in helping to manage water resources more effectively, assisting in preventing damage to infrastructure and supporting emergency preparedness and response in flood-prone areas. AI tools can optimize flood prevention measures, contributing to better decision-making and policy implementation for flood resilience.

Adverse Climate and Environmental Impacts of AI

As noted previously, the training of complex AI models, particularly deep learning networks, requires immense computational power, often running on large-scale data centers that consume vast amounts of electricity. If the energy powering these data centers is derived from non-renewable sources, it can lead to a substantial increase in carbon emissions, contributing to climate change. Additionally, the growing demand for AI technologies is directly linked to an increase in hardware production and e-waste, exacerbating environmental challenges related to resource extraction and disposal.

Energy Consumption and Carbon Emissions: Training state-of-the-art AI models, such as deep neural networks, demands significant computational resources, which in turn require considerable energy consumption. For instance, training models like Chat GPT can take weeks of continuous processing across hundreds of GPUs or specialized hardware, such as TPUs (Tensor Processing Units), housed in data centers. A study by Strubell et al.[10] has estimated that training a large-scale language model could produce as much carbon as five times the lifetime emissions of an average car. The environmental cost of these models is compounded when fossil fuels are used to generate electricity to power the data centers. As AI models grow in size and complexity, their carbon footprint increases, raising concerns about the sustainability of current AI research practices.[10]

E-Waste and Resource Depletion: AI's rapid evolution also contributes to the environmental burden through hardware production and the disposal of outdated technology. Data centers, which house the servers and other equipment used for training and deploying AI models, require high-performance hardware that often has a limited useful lifespan due to rapid technological advancements. This contributes to the generation of electronic waste (e-waste), which is difficult to recycle and contains toxic materials. The extraction of rare earth metals and other materials required for AI hardware production also has adverse environmental impacts, contributing to deforestation, pollution, and the depletion of natural resources.

Water Usage in Data Centers: Data centers, in addition to their high energy demands, also require significant amounts of water for cooling purposes. Liquid cooling systems are essential to prevent hardware from overheating during the extensive computations involved in AI training. As the demand for AI grows, so does the water consumption of data centers, raising concerns about their water footprint, especially in regions where water resources are already under stress. Another issue is the apparent conflict between reducing carbon and water footprints. Optimization of carbon footprints may lead to locating the data centers in hot areas where solar power can be derived from extended exposure to the sun. However, water usage by data centers in these regions may be of much significant concern because of the already hot climate and scarcity of water in these areas.

Discussion and Conclusion: Solutions and Mitigation Strategies

Efforts are being made to mitigate the environmental impact of AI, particularly by shifting towards greener and more sustainable AI practices. Optimizing algorithms for energy efficiency, investing in energy-efficient hardware, and transitioning data centers to renewable energy sources can help reduce the carbon footprint of AI. Google, for instance, has committed to using 100% renewable energy for its data centers and aims to achieve carbon-free operations by 2030. Additionally, researchers are exploring ways to make AI models more efficient, thereby reducing the need for vast computational power.

Besides these initiatives, a lot can be done by companies and the general population using AI-based tools, particularly large models, such as ChatGPT, to reduce environmental and climate impact. Transparency by companies on the carbon, climate and environmental footprint of AI technologies will educate general populations.

Besides training in large datasets, the use of AI tools by people worldwide has been seen to cause a significant climate and environmental footprint. It is noted by Kerr[20] that "One query to ChatGPT uses approximately as much electricity as could light one light bulb for about 20 minutes," he says. "So, you can imagine with millions of people using something like that every day, that adds up to a really large amount of electricity." Awareness about this among the general population will encourage people not to use these large AI models for trivial and mundane tasks. Specifically, AI tools companies should provide, as a warning to a user of AI tool, such as ChatGPT, on the amount of greenhouse gas emissions generated for per hour use of the tool.

The carbon and environmental footprint of AI can also be reduced by locating large data centers in regions with a large availability of renewable energy. The heat generated by data centers can be harvested for applications such as heating homes. For example, the largest Data Center in Finland will heat about 20 thousand houses. This project will reduce CO_2 emissions by 103 thousand tons, which is equivalent to 55 thousand vehicles.[9]

With explosive growth in the development, deployment, and usage of AI tools and a relatively slower pace of reduction in carbon and environmental footprint, the overall impact of AI on emissions will become significantly worse and reach a plateau before reduction. Measures such as improved transparency by companies training and developing AI tools, increased reliance on renewal energy sources, more efficient computer hardware and algorithms/software, efficient AI models, innovative cooling methods not relying on water for cooling and collective understanding of the public on the scale of energy and environmental problems posed by AI are necessary towards developing a sustainable AI. AI should not be used as a tool for trivial work but should only be used for difficult and important tasks where the return is significantly higher than the cost to the environment. Companies should also not make AI models and tools freely available to prevent their abuse by the public.

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