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Effects of AI on the environment

Word limit: 5000 words

Table of Contents:

The consequences of Artificial Intelligence on the Environment

Abstract

Considering the strength with which it shook technology, Artificial Intelligence is sure to be a topic of conversation within all ranges of research and science. As with anything that helps us further push our technological barriers, our species easily forgets to second guess our creation in contrast with the environment. Today we face the uprising of AI, and as we stand aside and watch it take over all sorts of technological ends, we wonder the toll nature will pay for this advancement. In this research, the environmental cost of the growing use of AI is analyzed to conclude the negative and positive contributions. Through the analysis of the different stages of production of AI models, from material sourcing to model testing, and the scrutiny of modern adoption and future predictions of popular usage, we conclude the overall environmental impact of Artificial Intelligence on our planet. The outcome is limited by the constantly changing methods of production and sourcing, but beyond the clear present implementations of AI towards helping the environment, the negative costs that come with these advancements is strongly present in all aspects of development.

Argumentation and Motivation

Environmental change and damage is a modern and influential topic of discussion, especially when looking towards solutions. We aim to investigate, analyze and conclude what the consequences of AI are on the environment. We are motivated by the urgency of this topic, and by the sense of contribution to possibly helping our own planet. This issue intertwines within different subjects, making it influential in many fields. The consequences of AI are vaste and have a full spectrum of effects on society and all its faces [1]. With the many positive changes

that this technological advancement is bringing to this world, an accurate assessment of the negative contributions to the environment is in order.

Background Context

Today's world is dependent on technology, artificial intelligence exponentially amplifies this dependence as more and more tasks rely on it. Today there is hardly a topic that has not been affected in a way by AI. In the research paper *Sustainable AI: Environmental Implications* (Wu et al.)[1] Artificial intelligence is analyzed methodically to discuss the negative and positive implications on the environmental scale. In our research, the different models of growth in terms of AI are argued and discussed, to output an unbiased conclusion in regards to themes such as carbon footprint, and data and infrastructure growth.

Relative Definitions

Artificial Intelligence (AI) - Computer systems that operate regularly tasks that would normally require human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages.

Machine Learning (ML) - A computer system able to adapt and learn from situations using algorithms and statistical models.

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[1] C.-J. Wu *et al.*, "Sustainable AI: Environmental Implications, Challenges and Opportunities".

Sustainable AI - AI used parallel to sustainable guidelines or that is used to achieve sustainable development goals.

Environment - The surroundings or conditions in which one lives or operates.

Sustainability of AI - AI which has limited carbon emissions and computing power, therefore reducing environmental pollution.

Ecological Integrity - the ability of an ecosystem to support and maintain its ecological processes, as well as a diverse community of organisms within it.

Environmental Resources - living and nonliving components that make up a biophysical environment.

AI Testing - Tests conducted with AI to further leverage it, to improve performances.

Relevance

To modern generations environmentalism is a topic central to their life. Besides guiding political and social orientation, it defines the small and large choices of many people. To further show the importance of environmentalism in modern society, in finances, many banks now tend to orient their campaign towards nature friendly choices to attract that large interested demographic. With artificial intelligence being such a strong component of most modern office and scientific roles, people are looking to know the real cost of this tool, the consequences on the environment. This research is aimed at analyzing the consequences of AI and ML to conclude the benefits and drawbacks of its explosion.

Goals of this Research

The growth of AI is exponential as its use is becoming increasingly relevant. However, further than its positive effects on technology, research, and development, there are consequences that negatively affect the environment. Whether these are created by the limitations of this tool, or the costs of its use, they have to be taken into consideration when evaluating it and expanding its applications. The goal of this paper is to locate and analyze possible consequences of AI and ML, in both a positive and negative way, on the environment, as well as assess their effect. Analyzing scientific literature pieces, we will draw unbiased results, to determine the damage AI and ML contribute to the environment.

Methodology

With its explosive impact on society, AI is a difficult topic to research into, as it falls under nearly every modern subject of discussion. To preserve the results from bias, this research will consider AI for both its positive and negative contributions to the environment. Normally as a powerful and versatile tool, AI has made its presence tangible in science for its vaste applicability in helping environmental problems. Saving and reducing, optimizing and incrementing are keywords highlighting only some of the many utilities AI and ML have shown themselves capable of when asked to help regarding the environment. On the other hand, aspects such as costs, energy consumption and expectations of future growth mostly focus on the implications of AI on our environment. In this research, the full spectrum of implications of artificial intelligence on the environment is analyzed and processed to produce a decisive unbiased report.

To methodically carry out this research, the steps that led to fundamental decisions will be listed and explained, in order to institute methods replicable by other researchers that lead to true results. AI, or more generally ML (Machine learning) and AI (Artificial intelligence) , constitute a research query that needs specifying. For this reason, the many aspects that compose these subjects in this methodology will be analyzed separately and the singular conclusions will be brought together in a final analysis.

Discussing the consequences of ML and AI on the environment needs strategic thinking and organization. For this, we will analyze these technologies from angles of *production, testing/development and usage*. Production refers to the process of making and testing of AI and ML, focusing on the before-testing phase. Testing/Development focuses on the experimental phase of AI, where majority energy is used. This point of discussion is strongly relevant, as testing AI and ML can lead to profound carbon emissions and extremely long running experiments. Lastly, considering usage of AI and ML will help determine the social end of these consequences. With these three different searching criteria, we can now search data to analyze.

To begin the search, we have to collect literature research that satisfies our queries. Preferably the sources come from research of 10 years maximum or younger and should come from various scientific backgrounds. To gather sources we look for search queries and keywords on research databases. Examples of these platforms are *Google Scholar and Science Direct*, from which many attendable sources can be found. To pass the first selection, articles have to provide some spectrum of answers to our search queries. These are:

RQ 1: What are the environmental consequences of an increased development and usage of artificial intelligence?

RQ 2: What are the environmental consequences of an increased development and usage of machine learning?

RQ 3: What has machine learning contributed to helping with environmental problems?

RQ 4: What has artificial intelligence contributed to helping with environmental problems?

RQ 5: What are projections of artificial intelligence in environmentalism?

The search queries used to gather sources (For more vaste search) are:

Artificial intelligence and environmentalism - Computer based intelligence in relation to environmentalism.

Machine learning and environmentalism - study of algorithmic statistics in relation to environmentalism.

AI and ML environmental impact - The negative effects of AI and ML on the environment.

Environmental consequences of AI/ML popularity - The negative consequences of the growing popularity of AI and ML on the environment.

AI and ML Testing - The developing phase of AI and ML where experiments and training is carried out.

AI and ML Co2 emissions - emissions caused by relation to AI and ML.

AI and ML Optimization - Applications and uses of AI and ML in relation to optimization

AI and ML environmental applications - Applications in support of the environment that use AI or ML.

AI and ML cooling emissions - Emissions generated by cooling of AI and ML hardware.

Researches and articles that result from searching the above sentences, and that present answers to at least one of the research queries pass the first layer of selection. Furthermore, to conclude if these sources have attainable and useful material for our analysis, they have to pass the second layer of selection. Here papers are read and organized per relevance and angle of research. Beside these grouping, sources are further selected based on these criteria:

- Year of release: up to 10 years ago
- Concludes results that reflect one or more of our research queries
- Methodology and Data: data, statistical claims, case studies, have to be supported in the literature
- Consistency and relevance: the source research lines with the overall goal of this research

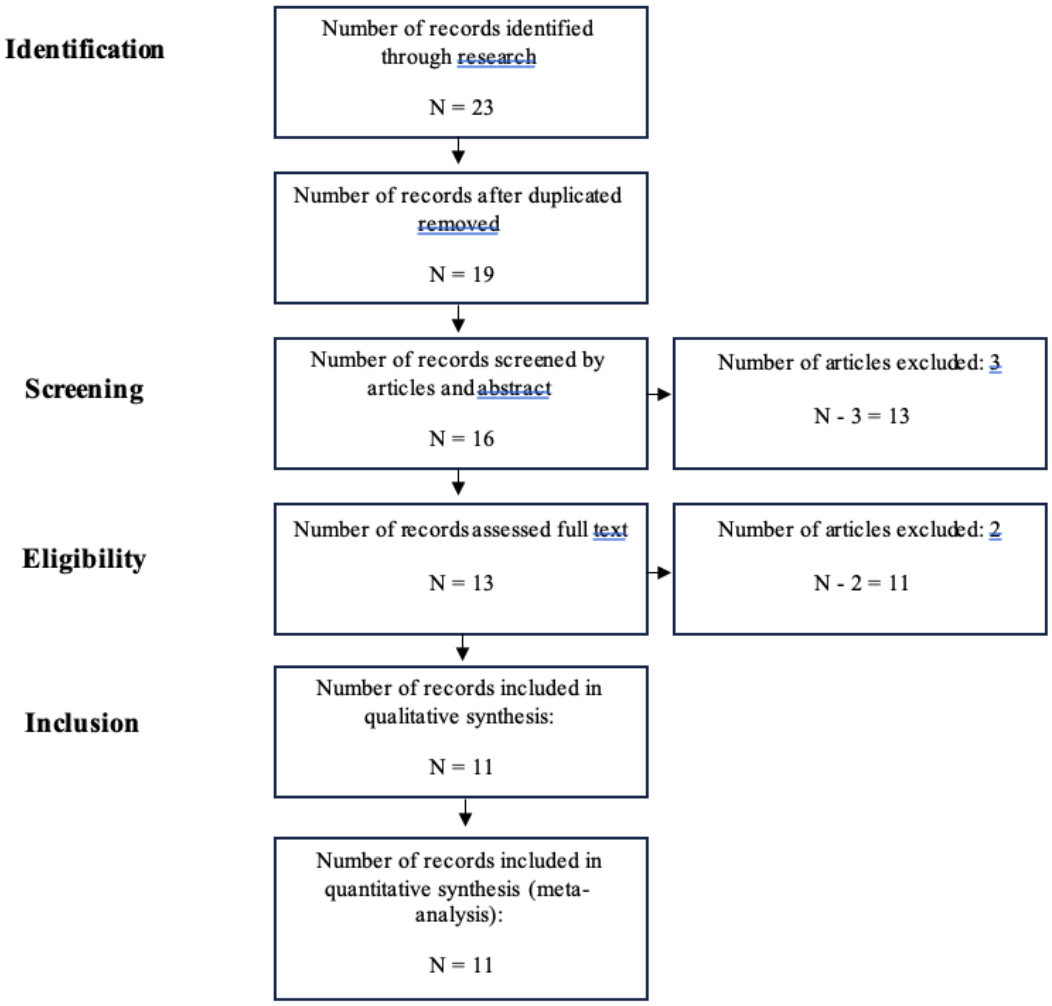

Figure 1: Flowchart runthrough of the methodology followed.

Source #	Relation to Co2 Emissions	Energy sources and Renewable energy integration	Relation to Popular Usage	Relation to Positive Effects	Future predictions	Background of research
1	Day-to-day analysis for what and how hardware-softw are design and at-scale optimization can help reduce the overall carbon footprint of AI.	Energy sources for AI are not green, optimizing softwares has helped reduce emissions, but greener sources would be better.	Narrowing applications of AI for given tasks. Optimizing usage.	Efficiency and optimization	AI being applied to predict renewable energy availability to improve energy utilization.	Elkin, C. and Witherspoon, S. Machine learning can boost the value of wind energy, 2019. URL https://deepmind.com/blog/article/machine-learning-can-boost-value-wind-energy. In a search to the problem from Google - Carbon-free technologies have not reached their full potential.

2	Carbon emissions create by AI and ML AI emits the most during training	There is no guidelines to what green AI even is, so its vague and conceptual	Computations. Data collection and analysis.	Uses of AI and implementations for research (also in relation to the amounts of carbon that are emitted)	Methods to decrease the emitted carbon and future plans to decrease based on its uses (by specific given companies)	Kate Crawford and Vladan Joler's award-winning visual map and essay, titled 'Anatomy of an AI system' assessing the impact of an artificial intelligence (AI) device on a global scale in terms of human labor, data and resources that are required during its lifespan, from manufacture to disposal, using Amazon's Echo as an example.
3			Operational transformations.	Research and automation. Operational performance. Technology Adoption and Green Supply Chain Management	AI unlocks possibilities for humans.	

4			Characteristics, limitations, and advantages of AI technologies used for environmental pollution research. Development of AI.	Feasibility and perspective of AI used in environmental fields. Accuracy of AI predictions (allow exclusion of complex mathematical formulas - input vs output for given studies)	Future challenges of AI are discussed.	
5	As AI applications grow the energy there are significant increases in energy consumption. Encourage the research to be done using new optimal methods of AI, in order to reduce computational and environmental costs.		Generate and analyze large data.	AI can help to reduce the effects of the climate crisis and develop low-emission infrastructure and modeling climate changes.		Tracking of energy consumption and regional CO2 emissions accounting.

6	Minimizing energy consumption and keeping a low carbon footprint.		Data analysis Mathematical and scientific models and design	Reduction of power consumption using correct AI architecture and implementation.		Keeping track of percentages relating to the use of AI for different purposes. Looking over the potential uses of AI over the past decade.
7	Author mentions the importance of energy requirements, because more AI = more data = more energy = more storage = more energy […]		Kids in schools, inspirational tool, Also cheating, faking implications.	Positively, accessible to all, free technology, creative tools, optimization of systems	Artificial Intelligence is a key component shaping the future: Job replacement, political bias, historical records being influenced by societal problems. (loss of knowledge jobs)	
8	Confirming and measuring the increase in the carbon footprint with the use of multiple AI software.		Technological advancements, measuring and data collection. Data optimization and analysis.			Measuring the carbon intensity in cloud computing.
9	reducing emissions of AI - the limitations of using it			designing AI for green predictions		

10			Emissions of first order impacts of AI services	Monitoring, data analysis, communication, information storage and retrieval can be improved and enhanced with the use of AI.		"The goal of this paper is to show how Artificial In- telligence in particular and Information Technologies, in general have succeeded in developing adequate tools for modeling, design, simulation, prediction, planning and decision-support systems for environmental man- agement and protection."

Figure 2: Synthesis matrix of sources used and relation to the sub topics discussed in the paper.

Data Encoding

The shockwave from AI and ML explosive popularity has contacted and significantly influenced a variety of sectors, making a new era of innovation and efficiency seem not far from reality. The fast advancement of this technology has raised worries in regards to the environmental consequences of all this.

Through the following coding criteria, this research will analyze and investigate the complicated effects of AI and ML on the environment. This study will evaluate the environmental impact of AI and ML, its relation to CO2 emissions, as well as sources of energy, and its adaptation to renewable energy sources. Moreover, we will analyze the cost of popular usage of AI and ML and go over the positive effects and future prediction of these technologies.

Relative CO2 emissions - An assessment of the CO2 emissions of various activities involving AI and ML in comparison with other sectors or techniques.

Sources of energy and adaptation to renewable energy - Examining the sources of power with which AI and ML operations are carried out, and a focus on the feasibility of an ecological transition.

Popular usage - An evaluation of the many popular applications that affect the day to day of modern people, and the environmental consequences of these actions.

Positive effects - An evaluation of the positive applications and effects of AI and ML.

Future projections - Discussion of trends and future projections of growth and adaptation of AI and ML.

Results:

Relative CO2 Emissions

Reduction and optimization are terms familiar to AI and ML related works. This powerful tool has made its presence clear even in the early stages of development, by effortlessly optimizing systems of large complexities, showing one of its strongest applications. Given this sense of miraculous work, we are led to believe that AI is here to fix things. But with a holistic approach, you immediately notice the inevitable problem created by this new technological frontier. Due to its large computational requirements, AI and ML systems require lots of energy, infrastructure and maintenance, which all require power. This huge need for power has led the field to start generating large amounts of CO2 emissions, as renewable alternatives for power sources are not as accessible.

Many of the papers brought attention to the CO2 emissions of AI. As it scales up both commercially and technologically, the many speculations of growing CO2 emissions mentioned in our papers, are funded on the already large CO2 emissions outputted by these systems. To further explain, there are many reasons why AI pollutes this much. Most strongly, in its training stage, computation can stay so high for so long that a single large size training can emmitt as much as 300.000Kg[3] of CO2[2], as table 1, from source 1 illustrates. To give scale to the size of this issue, five of our eleven papers [1, 2, 3, 4, 5] shared concerns regarding some aspect of AI caused emissions. A research measuring the carbon emissions of cloud and AI instances, concluded that the largest amount of computation workload falls on one component of the computer to consume more and raise in heat. After running experiments, the researchers concluded that running a basic AI model on a 256GB Ram system, 74% of computational workload was carried out with the GPU[3], as displayed in table 3 from that same source. Consequently, another concern shared among the researchers is the need for cooling caused by these processing needs. Infrastructures and cooling are the other two determinants of AI caused pollution.

Source 6 raised a point worth expanding. AI has gained rapid popularity among average internet users, and the scaled production due to this new need has already proven to be inevitably emitting large amounts of carbon. The researchers shared a concern regarding the

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[2] P. Dhar, "The carbon impact of artificial intelligence," *Nature Machine Intelligence*, vol. 2, no. 8, Art. no. 8, Aug. 2020, doi: 10.1038/s42256-020-0219-9.

[3] "Role of artificial intelligence in operations environment: a review and bibliometric analysis | Emerald Insight." Accessed: Sep. 19, 2023. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/TQM-10-2019-0243/full/html

future predictions of CO2 emissions caused by AI, as it becomes more powerful, it will need more energy, more space, more cooling, little of which comes from renewable sources.

Sources of energy and adaptation to renewable energy

Without electricity, there is no Artificial Intelligence, therefore tracing the sources of energy AI and ML providers choose, is crucial in understanding the overall carbon footprint of these operations. Four of the eleven selected sources tackled this topic [1, 2, 6, 7]. These sources shared concerns regarding the need to switch to a sustainable AI. Source one [2] illustrates this problem through an infographic [Image 1]. In their research, they uncovered and determined the percentages of sustainable, and not, energy usage from large AI and ML providers or users. In this table it is clear that a large component of the operational carbon footprint of these large ML tasks is sourced from carbon-free power plants, which reduces the overall impact generously. Therefore the remaining concern is to do with the manufacturing of AI and ML, which as mentioned before, is responsible for the largest amount of carbon emissions caused by AI. Similarly, source 2 shared concerns regarding the importance of determining what sustainable AI is. As there is no specification of what sustainability may look like in artificial intelligence, experts are hesitant to talk about the future of AI in environmentalism. As of now, as discussed in source 2, manufacturers have no obligation or incentive to switch to renewable sources, and the lack of specification of what that may look like, pushes developers further from the switch.

The future of AI is dependent on the choices we make now, and for that, defining sustainable AI is a priority before pushing further developments of these technologies.

Popular usage

Undoubtedly, the nature of AI has allowed it to take a role in a variety of sectors and fields. We have seen AI bring a step forward in agricultural development, and it has made itself very useful in data analysis and many other computational roles. With this much potential AI and ML are predicted to embed within our technology and society in no time.

To predict the tendencies and shapes AI and ML may take in the future, we have to consider the modern areas of interest that have seen a more profound change since the arrival of these technologies. As it has been said many times in this paper before, few ends have not been affected by artificial intelligence in the past 3 years. Though many ends show tendencies of stronger connection to AI and ML, which may lead to a burst of growth as these technologies continue to develop. Because of this, to have a holistic understanding of the effects of AI and ML on the environment we must pay close attention to what could potentially be growing causes of pollution. Out of the reviewed sources, eight of the eleven sources [1, 2, 3, 4, 5, 6, 7] analyzed some facet of AI popular usages and its emissions. To the furthest extent, an extensive article analyzing the hidden environmental impact of AI [8] discussed the first-order impacts of AI services, which refers to the emissions generated globally (on every end of the manufacturing) of AI service providers. In this paper, every step of the process, from mining minerals to storing data for service reasons, is taken into consideration for its environmental impact. Backed by the other seven sources, the review shared concerns for the growing size of these services, for the emissions will only continue to grow. Generally, AI and ML applications can be narrowed down to the task it completes. For instance, AI can be used for data optimization or data analysis, which can be for finance, health or governmental reasons. Source

nine highlights the importance of seeing the positives and negatives of the contributions of AI and ML [7]. This perspective reflects well with the theme of optimization discussed in source one [2], which is also touched upon by almost every source. AI and ML have been able to streamline processes that were previously more intensive. An example of this, can be seen within a strong application of AI, in predictive maintenance in industry. This allows for productions to be more easily up to environmental standards, and as a consequence of that, global operations have been able to reduce their gross emissions.

Positive effects

As mentioned in the previous paragraph, the environment has partially benefited from the explosive popularity of artificial intelligence with its many modern applications. AI has contributed to helping the environmental problem in a variety of ways. Due to its vaste applicability, AI and ML have been a helpful tool when fighting emissions, over consumption, and streamlining data management. In this research, six of the ten selected sources reflected on the positive contributions of AI [1, 2, 3, 4, 7, 8]. Among the discussed applications, AI has made itself more loudly present in fields regarding large amounts of data. Source six [3] discussed the possibility of being able to reduce power consumption by more than 50% just by applying the correct AI model architecture, a claim backed by the other five sources. Source nine [7] complained about a lack of fair evaluation, when considering the true effectiveness of AI on helping the environment, a concern shared by the other sources too. Though source nine further explained the relation between the life cycle of materials with the environmental applications of AI and ML. Without knowledge of the real cost of developing AI and ML

models in terms of life cycle and training, it is hard to quantify the final aid AI has contributed to the environment.

Future predictions

The future of AI and ML, in the various used papers, discuss predictions in terms of: use, development and environmental impact. Although some seem dystopian, experts forecast great changes in our society. Opinions range in discussion from the future of jobs, to worries for emissions and hardware production. In the papers used for this research, the greatest worries rose from a considerably inevitable cost of the upscaling of AI and ML. The growing manufacturing needs, constant sourcing of energy, server cooling and growing infrastructure, represent threats to our Environment, as the development of these technologies proceeds unregulated.

Numerous papers discussed the Life-Cycle of machine learning and of the hardware needed for storing and processing data. The concerns in regards to these topics are founded in the models for predictions of growth, models such as *Moore's Law*, have a range of accuracy that worries experts, and AI pushes the limits of this function with shockingly fast development and growth. A paper rigidly states the computational growth of AI has been less than two times every 2 years [2], an astonishing amount considering the computational size and amount of data stored. Furthermore, four of the collected papers raised concern regarding the growing size of data computation and it equals a direct growth in energy needs, infrastructure, hardware production, and all the smaller components of this operation [1, 2, 4, 9].

It comes without saying that Artificial Intelligence has made itself a name for its most inviting applications: reduction and optimization of processes. Within the research process of this paper, countless were the papers that analyzed AI against challenges such as: Energy

optimization, AI methods for water reduction or titles such as “AI associated with carbon emissions reduction”, because of titles like this, a future full of AI based energy saving is negligible. Although not all these papers made the final selection for our research, it is worth noticing the large amounts of data connecting AI and ML to energy optimization in many fields. The future predictions concerning the growth of Artificial Intelligence scare experts, as the lack of guidelines and restrictions leaves *green AI* [1] conceptual and vague.

Conclusion

The deeper implications of the increasing popularity, usage and development of AI and ML are still vague in these early stages of this technology. Regularly we find more applications for AI that contribute to some end of optimization, which complicates the estimation of how much is saved in comparison to how much it costs. These research concludes to the possible extent the effects of AI on each criteria used. Furthermore, It is too early to conclude the extent to which AI can help us fight climate change, as development and updating continues. This research was limited by the availability of background research, as the topic of interest has recently gone through tremendous changes and growth. In fact, the greatest threat to environmentalism from Artificial Intelligence is the lack of definitions and guidelines. As of the time of this research, terms such as sustainable AI have no real definition, which leaves more choices regarding energy sources and emissions to the makers. Through the analysis of the full spectur of development of AI this research was able to determine the gray areas in this technological advancement. The consequences of an increased development and usage of AI and ML will inevitably cause an increased demand for the necessary physical components, infrastructure and data storage, which come with a cost for the environment. Beyond that, even in these early stages, the contributions of AI and ML have to be recognized. Data management and energy optimization have already shown great worth in environmentalism, as more and more applications become standard practice. The CO2 emissions in relation to Artificial intelligence remaining closely tied to the sourcing of the materials needed to build components, but as populare usage grows in size the generated by-product gasses may grow with it. To conclude, the future effects of artificial intelligence on the environment remain vague, as

development increases, so do the applications and power of the models available, which leaves room for hope for answers and solutions from these technologies.

Articles retrieved from searching but not used:

[1]

C.-J. Wu *et al.*, "Sustainable AI: Environmental Implications, Challenges and Opportunities".

[2]

X. Xiang, Q. Li, S. Khan, and O. I. Khalaf, "Urban water resource management for sustainable environment planning using artificial intelligence techniques," *Environmental Impact Assessment Review*, vol. 86, p. 106515, Jan. 2021, doi: 10.1016/j.eiar.2020.106515.

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"Role of artificial intelligence in operations environment: a review and bibliometric analysis | Emerald Insight." Accessed: Sep. 19, 2023. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/TQM-10-2019-0243/full/html

[4]

M. D. Renzo *et al.*, "Smart radio environments empowered by reconfigurable AI meta-surfaces: an idea whose time has come," *J Wireless Com Network*, vol. 2019, no. 1, p. 129, May 2019, doi: 10.1186/s13638-019-1438-9.

[5]

S. Benzidia, N. Makaoui, and O. Bentahar, "The impact of big data analytics and artificial intelligence on green supply chain process integration and hospital environmental performance," *Technological Forecasting and Social Change*, vol. 165, p. 120557, Apr. 2021, doi: 10.1016/j.techfore.2020.120557.

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[1] P. Dhar, "The carbon impact of artificial intelligence," *Nature Machine Intelligence*, vol. 2, no. 8, Art. no. 8, Aug. 2020, doi: 10.1038/s42256-020-0219-9.

[2] C.-J. Wu *et al.*, "Sustainable AI: Environmental Implications, Challenges and Opportunities".

[3] A. Konya and P. Nematzadeh, "Recent applications of AI to environmental disciplines: A review," *Science of The Total Environment*, vol. 906, p. 167705, Jan. 2024, doi: 10.1016/j.scitotenv.2023.167705.

[4] "Generative AI: Here to stay, but for good?," *Technology in Society*, vol. 75, p. 102372, Nov. 2023, doi: 10.1016/j.techsoc.2023.102372.

[5] "Measuring the Carbon Intensity of AI in Cloud Instances | Proceedings of the 2022 ACM Conference on Fairness, Accountability, and Transparency." Accessed: Nov. 10, 2023. [Online]. Available: https://dl.acm.org/doi/abs/10.1145/3531146.3533234

[6] S. A. Budennyy *et al.*, "eco2AI: Carbon Emissions Tracking of Machine Learning Models as the First Step Towards Sustainable AI," *Dokl. Math.*, vol. 106, no. 1, pp. S118–S128, Dec. 2022, doi: 10.1134/S1064562422060230.

[7] A.-L. Ligozat, J. Lefèvre, A. Bugeau, and J. Combaz, "Unraveling the Hidden Environmental Impacts of AI Solutions for Environment." arXiv, Apr. 21, 2022. doi: 10.48550/arXiv.2110.11822.

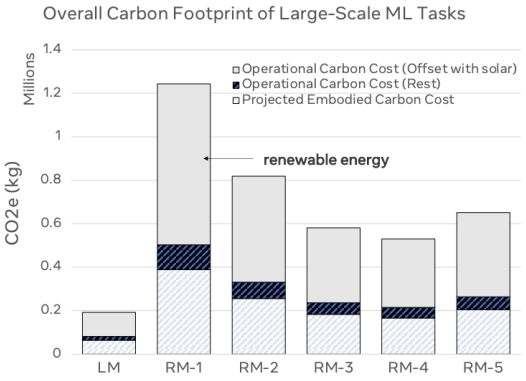
[8]
U. Cortés, M. Sànchez-Marrè, L. Ceccaroni, I. R-Roda, and M. Poch, “Artificial Intelligence and Environmental Decision Support Systems,” *Applied Intelligence*, vol. 13, no. 1, pp. 77–91, Jul. 2000, doi: 10.1023/A:1008331413864.

[9]
Z. Ye, J. Yang, N. Zhong, X. Tu, J. Jia, and J. Wang, “Tackling environmental challenges in pollution controls using artificial intelligence: A review,” *Science of The Total Environment*, vol. 699, p. 134279, Jan. 2020, doi: 10.1016/j.scitotenv.2019.134279.

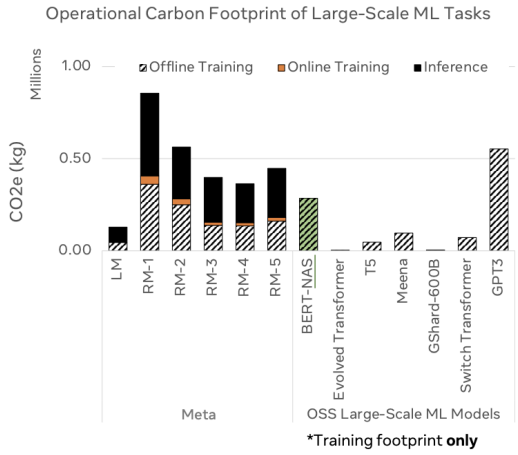
[10]
“Role of artificial intelligence in operations environment: a review and bibliometric analysis | Emerald Insight.” Accessed: Sep. 19, 2023. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/TQM-10-2019-0243/full/html

[11]
A. van Wynsberghe, “Sustainable AI: AI for sustainability and the sustainability of AI,” *AI Ethics*, vol. 1, no. 3, pp. 213–218, Aug. 2021, doi: 10.1007/s43681-021-00043-6.

Appendix



[Table 1]



[Table 2]

Hardwa.	GPU	CPU_0	CPU_1	$DRAM_0$	$DRAM_1$	*Total*
Watts	187.1	22.9	9.3	23.0	9.3	251.6
Fraction	74%	9%	4%	9%	4%	100%

Table 1: The electricity consumption, in watts and percentages, when training BERT base on a single NVIDIA TITAN X GPU (12GB), in a commodity server with two Intel Xeon E5-2630 v3 CPUs (2.4GHz) and 256GB RAM (16x16GB DIMMs). Power consumption is averaged across instantaneous measurements over 12 hours of training on using the masked language modeling objective. The GPU alone accounts for 74% of the total energy consumption due to these components.

[Table 3]