First Draft for Increasing Computation Resources Impact on Environment

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Abstract

Artificial Intelligence is one of the fastest-growing paradigms spanning research and product development. Recent breakthroughs in large language models have increased the use of AIs not only in big domains like science, education, medicine, and finance but also in day-to-day life activities. Big companies like Google, Microsoft, OpenAI are competiting with each other in building AIs which can be made availabe to the public. With the availability of these products, the cost of computation is often neglected when using these large language models. Heavy computation resources like GPU and data warehouses are used not only to train these models but also for inferencing for further tasks. This survey focuses on these computation resources and their impact on the environment on a large scale. We will also focus on the measures which are being taken to control it.

1 Introduction

Scaling Law (Kaplan et al., 2020) has sparked an innovation in creating language models with billions of parameters for to multitude of tasks from one model. Therefore models GPT-3/4 (Brown et al., 2020), Falcon (Almazrouei et al., 2023), and Google Gemini (Team et al., 2023) have billions of model parameters. Training and making the models publically available comes with a cost of computation resources. For example GPT-4 Runs on clusters of 128 A100 GPUs.

In terms of training a large language model, each processing unit can consume over 400 watts of power while operating. Typically, you need to consume a similar amount of power for cooling and power management as well. Overall, this can lead to up to 10 gigawatt-hour (GWh) power consumption to train a single large language model like ChatGPT-3. This is on average roughly equivalent to the yearly electricity consumption of over 1,000 U.S. households. Today there are hundreds of millions of daily queries on ChatGPT, though that number may be declining. This many queries can cost around 1 GWh each day, which is the equivalent of the daily energy consumption for about 33,000 U.S. households. While these numbers might seem OK for now, this is only the beginning of a wide development and adoption of these models.

Data and AI growth The ever-increasing data volume has driven a super-linear trend in model size growth. Despite being small, the accuracy improvement leads to significantly higher-quality search outcomes because deep learning techniques can consider the rich context in search queries effectively. Similarly, between 2019 and 2021, the size of recommendation models at Meta has increased by 20× into the terabyte scale. Despite the large model size growth, the memory capacity of GPU-based accelerators, e.g. 32GB (NVIDIA V100, 2018) to 80GB (NVIDIA A100, 2021), has increased by < 2× every 2 years. The resource requirements for strong AI scaling outpaces that of system hardware.

Infrastructure Growth Increasing model size demand for a variety of scale-out solutions (Ginart et al., 2021) by leveraging parallelism at scale with a massive collection of accelerators. The explosive growth in AI use cases at Meta has driven a 2.9× increase in AI training infrastructure capacity over the last 1.5 years. In addition, we observe trillions of inferences per day across Meta's data centers—more than doubling in the past 3 years. The increase in inference demands has also led to a 2.5× increase in infrastructure capacity. Last but not least, the carbon footprint of AI goes beyond its operational energy use. The embodied carbon footprint of systems is becoming a growing factor in AI's overall environmental impact.

2 Problems

There is no doubt that recent innovations in AI and Machine learning have made a huge positive impact on society. But there is an endless search for achieving higher model quality which leads to higher model size and significantly increases the energy consumption and environmental footprint implications. Although recent work shows the carbon footprint of training one large ML model, such as Meena (Adiwardana et al., 2020), is equivalent to 242,231 miles driven by an average passenger vehicle (EPA, 2021),

Broadly, carbon emissions have two sources: operational energy consumption, and hardware manufacturing and infrastructure. Although carbon emissions from the former are decreasing thanks to algorithmic, software, and hardware innovations that boost performance and power efficiency, the overall carbon footprint of computer systems continues to grow. This work quantifies the carbon output of computer systems to show that most emissions related to modern mobile and data-center equipment come from hardware manufacturing and infrastructure

Chasing carbon (Gupta et al., 2021) shows that the dominant factor behind the overall carbon output of computing has shifted from operational activities to hardware manufacturing and system infrastructure. Over the past decade, the fraction of life-cycle carbon emissions due to hardware manufacturing increased from 49% for the iPhone 3GS to 86% for the iPhone 11. The Pareto frontiers illustrate a tradeoff between AI performance and carbon footprint. Across the 2019 performance/carbon-footprint frontier, the iPhone 11 Pro achieves a MobileNet v1 (Howard et al., 2017) throughput of 75 images per second at a manufacturing output of 66 kg of CO2; in comparison, the Pixel 3 achieves an inference throughput of 20 images per second with 45 kg of CO2. In addition to this tradeoff, the Pareto frontier between 2017 and 2019 shifts to the right, prioritizing higher performance through more sophisticated and specialized hardware. Although the iPhone X (2017) achieved a throughput of 35 images per second at 63 kg of CO2, the iPhone 11 (2019) doubled that performance at a slightly lower 60 kg of CO2. While greater performance is important to enabling new applications and improving the user experience, moving the Pareto frontier down is also important—that is, to mitigate the environmental impact of emerging platforms and applications, it is crucial to design workloads and systems with similar performance but lower environmental impact.

3 Quantifying Carbon Emission

While a decade ago, only a few ML pioneers were training neural networks on GPUs (Graphical Processing Units), in recent years powerful GPUs have become increasingly accessible and used by ML practitioners worldwide. Furthermore, new models often need to beat existing challenges, which entails training on more GPUs, with larger datasets, for a longer time. This expansion brings with it ever-growing costs in terms of the energy needed to fuel it. To quantify carbon emissions, we use CO2-equivalents (CO2eq), which is a standardized measure used to express the global warming potential of various greenhouse gases as a single number, i.e. as the amount of CO2 that would have the equivalent global warming impact (Van Amstel, 2006)

Another, more subtle, factor in carbon emitted by a neural network is the computing infrastructure used and the training time of the model. In terms of performance, the number of floating point operations per second (FLOPS) of GPUs has been steadily increasing in recent years, from 100 Giga FLOPS per second in 2004 to up to 15 Tera FLOPS per second in recent hardware. However, with neural network architectures becoming deeper and more complex, recent state-of-the-art models are often trained on multiple GPUs for several weeks (or months) to beat benchmark performance, requiring more and more energy. A few recent LLM papers reported the carbon footprint of model training, including notable models such as OPT-175B (Zhang et al., 2022), GPT-3 (Brown et al., 2020) and Gopher (Rae et al., 2022). Table 2 shows the comparison of different models with their energy consumptions.

Energy usages Carbon emission on large neural network (Patterson et al., 2021) vary from size and training methods.

- T5 (Raffel et al., 2023) is a pre-trained language model that casts all NLP problems in a unified text-to-text format to enable the application of transfer learning techniques to reduce the cost of training . The largest size has

11B parameters, and training used 86 MWh and produced 47 tCO2e.

- Meena (Adiwardana et al., 2020) is a multi-turn open-domain chatbot . This 2.6B parameter DNN is trained to minimize the perplexity of the next token. Training Meena used 232 MWh and emissions was 96 tCO2e.

- Switch Transformer (Fedus et al., 2022) simplifies the Mixture of Expert (MoE) routing algorithm to design intuitive improved models with reduced communication and computational costs [Fed21]. The authors show large sparse models—1500B parameters but only 0.1% activated per token—can deliver up to 7x increases in pre-training speed with the same computational resources. We estimated it used 179 MWh and produced 59 net tCO2e

4 Tools

- ML Emissions Calculator (Lacoste et al., 2019) This tool, currently in its alpha version, takes as input the details regarding the training of an ML model: the geographical zone of the server, the type of GPU, and the training time, and gives as output the approximate amount of CO2eq produced. We collected publicly available data for the 4 main variables of this computation: (i) the energy consumption of hardware, (ii) the location of providers' regions of compute – which we assumed to be connected to their local grid, (iii) the region's CO2eq emissions per kWh and (iv) potential offsets bought by the provider.

- freely available online tool, Green Algorithms (Lannelongue et al., 2021) (www.green-algorithms.org) is developed, which enables a user to estimate and report the carbon footprint of their computation. The tool easily integrates with computational processes as it requires minimal information and does not interfere with existing code, while also accounting for a broad range of hardware configurations.

5 Conclusion

The increasing demands of LLMs and never-ending research to find better models have resulted in the production of high carbon emissions. The rate of this emission if not monitored can lead significant impact on the environment. These impacts can be direct such as Global Warming, pollution, or indirect like causing health issues or endangering flora and fauna. The measurement of carbon footprints involves the lifecycle of the various components involved in data and training and the final deployment of the model. To quantize it we used a different framework but it still gives us the estimation of the actual numbers. Making better framework for measuring carbon footprints we can create better algorithms and process to reduce carbon emission throughout the process.

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Model Name	No of parameter	Energy consumption	Co2eq emission
GPT-3	175B	1.287 MWh	502 tonnes
Gopher	280B	1.066 MWh	352 tonnes
OPT	175B	324MWh	70 tonnes
BLOOM	176B	433MWh	25 tonnes

Table 1: Comparison of carbon emissions between BLOOM and similar LLMs. Numbers in italics have been inferred based on data provided in the paper describing the models.

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A Example Appendix

This is an appendix.