2024 HiMCM
Problem B: Examining the Environmental Impact of High-Powered Computing

As global demand for **high-powered computing (HPC)** continues to rise in sectors like artificial intelligence (AI), data science and cryptocurrency mining, so does the environmental footprint of these technologies. The increasing reliance on massive **data centers**, high performance hardware, and energy-intensive computational processes has sparked concern about their environmental consequences.

The most important aspect of the environmental impact of HPC is energy consumption and its associated carbon emissions. This aspect stands out as it has a direct contribution to climate change as energy consumption directly correlates with greenhouse gas emissions, particularly when electricity is generated from **fossil fuels**. These HPC facilities often consume vast amounts of energy, making their carbon footprint significant. Additionally, the energy demand can strain local power grids, especially in areas with limited **renewable energy** infrastructure leading to a higher reliance on non-renewable energy sources.

In addition to energy consumption, there are other environmental concerns. The additional environmental impacts of HPC are multi-faceted and can be categorized into several key areas:

- **Water Usage.** Many data centers use water for cooling leading to substantial water consumption and potential pollution with the discharge of their wastewater.
- **E-Waste.** The manufacturing, use and disposal of computing hardware contributes to electronic waste with many of the components being difficult to recycle.
- **Resource Depletion.** The production of HPC hardware involves the extraction of rare earth materials which can lead to habitat destruction, pollution, and additional demands for energy.
- **Land Use.** The physical space required for the data centers can lead to land use debates with significant impacts on the local ecosystems.
- **Air Quality.** This focuses on the emissions from fossil fuel power plants that can degrade air quality and affect human health. Additional consideration should also be given to fine particulate matter and dust generated by the data centers that impacts local air quality.
- **Chemical Use.** The cooling systems use chemicals that can pose a risk if not managed properly, including potential spills or leaks.

- **Socioeconomic Impacts.** Large data centers as well as the mining for resources can lead to changes in the land with the potential for inequities in energy access for local communities.
- **Noise Pollution.** All the operations involving machinery in every phase of this process can contribute to increased noise pollution impacting communities and wildlife.
- **Network Architecture.** The network infrastructure needed for data transmission extends beyond individual **nodes** to include greater connectivity concerns.

Many of these aspects have dedicated research into their environmental impacts that you can research and use as background into understanding the problem.

Requirements.

1. Understand the Problem. Describe the scope of this problem in terms of the annual energy consumption of the HPC capabilities worldwide considering both **full capacity** and **average utilization rates**.

2. Create Your Model. Develop a comprehensive model to determine the environmental impact of total carbon emissions resulting from energy consumption of HPC. Consideration should be given to how the energy is produced, accounting for **energy mixes**.

3. Apply Your Model.

a. Explore how your model may change in the future with the growth of HPC, the increasing demand for energy in other sectors and the potential for different energy sources and mixes.
b. Use your model to provide realistic bounds that can provide insight into the scope of the problem in the year 2030.

4. Expand Your Model and Reflect on Your Analysis.

a. Model the impact of increasing the portion of renewable energy and calculate the corresponding reductions in carbon emissions. Investigate the effects of switching to a 100% renewable energy source as well as the potential challenges involved.
b. Refine your model (or develop a new model) to include the environmental impact of one of the other key areas listed above to further understand the impact on HPC. Describe why your group chose that aspect and how it relates to other key areas, especially energy consumption.

5. Share Your Model and its Results.

a. Develop a set of actionable recommendations to reduce the environmental impact of HPC, considering both technical and policy-oriented solutions.
b. Assume one of your recommendations is acted upon. Determine and show how you can incorporate this into your model.

c. The United Nations Advisory Board issued a report on AI entitled "*Governing AI for Humanity*" in September 2024 without significantly addressing HPC.[1] Write a one-to-two-page letter to the Advisory Board urging them to include a more detailed section on the environmental impacts of HPC in their scheduled developmental goals for 2030. Use your findings and recommendations to support this plea.

Your PDF solution of no more than 25 total pages should include:

- One-page Summary Sheet.
- Table of Contents.
- Your complete solution.
- One- to two-page United Nations Advisory Board letter.
- References list.
- AI Use Report (If used does not count toward the 25-page limit.)

Note: There is no specific required minimum page length for a complete HiMCM submission. You may use up to 25 total pages for all your solution work and any additional information you want to include (for example: drawings, diagrams, calculations, tables). Partial solutions are accepted. We permit the careful use of AI such as ChatGPT, although it is not necessary to create a solution to this problem. If you choose to utilize a generative AI, you must follow the COMAP AI use policy. This will result in an additional AI use report that you must add to the end of your PDF solution file and does not count toward the 25 total page limit for your solution.

NEW HiMCM/MidMCM: Online Submission Process
The purpose of this article is to assist and guide students and advisors participating in HiMCM/MidMCM. In the article, COMAP, provides information about the new online submission process using the new online submission page https://forms.comap.org/242386224483964. You will need your team's control number, advisor id number and your problem choice to complete your submission.

Glossary

High-Powered Computing: Also known as high-performance computing (HPC), this refers to the use of supercomputers and parallel processing techniques to solve complex computational problems at high speeds.

E-Waste: Short for electronic waste, e-waste refers to discarded electrical or electronic devices. This includes computers, smartphones, televisions, and appliances that are no longer in use. E-waste is a significant environmental concern due to the hazardous materials it often contains.

Data Centers: Facilities used to house computer systems and associated components. Data centers provide the infrastructure for processing, storing, and managing large volumes of data and include servers, cooling systems, and backup power supplies to ensure reliable operation.

Node: A node in the context of network infrastructure is any device connected to a network that can send, receive, or process data. It's like a junction point where data can be transmitted, received, or modified.

Full Capacity: The maximum output that a power plant or energy source can produce under optimal conditions. It is often expressed in megawatts (MW) or gigawatts (GW) and represents the peak generation capability.

Average Utilization Rate: A measure of how effectively a power plant or energy source is being used over a specified period. It is calculated by dividing the actual output by the full capacity over the same period. This indicates how consistently a facility is operating compared to its full potential.

Energy Mix: The combination of different energy sources used to meet energy needs. This can include fossil fuels (coal, oil, natural gas), renewable sources (solar, wind, hydro, biomass), and **nuclear energy**.

Fossil Fuels: Energy sources derived from ancient organic matter, primarily coal, oil, and natural gas. These fuels are non-renewable and contribute to greenhouse gas emissions when burned.

Renewable Energy: Energy that comes from sources that naturally replenish themselves, such as solar, wind, hydroelectric, geothermal, and biomass. These sources are generally considered more sustainable and have a lower environmental impact.

Nuclear Energy: Energy produced through nuclear fission, where atomic nuclei are split to release energy. It is a low-carbon source but involves concerns regarding radioactive waste and nuclear safety.

References

[1] United Nations Advisory Board on AI (2024). *Governing AI for Humanity*. https://sdgs.un.org/goals

Ahmed, M., & Verma, A. (2023). A review on the decarbonization of high-performance computing centers. *Journal of Cleaner Production*. Retrieved from https://www.sciencedirect.com/science/article/pii/S0959652623004567

Goldman Sachs. (2023). *AI is poised to drive 160% increase in data center power demand*. Retrieved from https://www.goldmansachs.com