Environmental Impact of AI-Driven Data Centers
By Krish Garg

Background & Research Objectives:

Artificial intelligence has experienced rapid growth in recent years which has increased the need for data centers and large computing clusters. These facilities draw a large amount of electricity. Their emissions depend on the carbon intensity of the electric grid in the regions where they operate. Some regions in the United States have cleaner grids while others rely more on fossil fuels and therefore have higher emissions. Studies have documented the increasing energy demands of digital systems and the uneven environmental impacts associated with their location (Strubell, Ganesh, and McCallum, 2019). These studies include global overviews from the International Energy Agency and research on the energy needs of large machine learning models (International Energy Agency, 2023).

Less attention has been given to how the growth of AI computing interacts with the recent trend of grid decarbonization in the United States. The goal of this study is to connect these trends. It examines how grid emissions have changed over time and how current spatial patterns may shape emissions from AI growth. It also compares these conditions with recent increases in data center electricity use. The primary objective is to determine whether cleaner grids are sufficient to offset the rapid growth in electricity demand for AI.

Sources of Data and Description of Analyses/Methods:

Electricity grid emissions data were obtained from the United States Environmental Protection Agency's eGRID reports for the years 2012 through 2023 (U.S. Environmental Protection Agency, 2023). These six regions were selected – CAMX, NWPP, ERCT, RFCW, SRVC, and NYUP. These regions represent both high and low carbon intensity and include several data center hubs. The values were measured in pounds of carbon dioxide per megawatt hour.

Electricity use estimates for data centers and AI workloads were taken from the International Energy Agency. Values reported in the dataset are in terawatt hours and includ values for 2020, 2023, 2024, and a projection for 2030.

				Base		Lift-Off		High Efficiency		Headwinds	
	2020	2023	2024	2030	2035*	2030	2035*	2030	2035*	2030	2035*
Electricity consumption (TWh)											
Total	**269**	**361**	**416**	**946**	**1 193**	**1 264**	**1 719**	**792**	**972**	**669**	**707**
Hyperscale	100	148	166	378	466	479	626	397	472	279	293
Colocation and service provider	85	112	144	355	493	482	721	385	490	246	285
Enterprise	85	100	106	213	234	303	372	10	10	144	128
IT	**176**	**252**	**295**	**733**	**985**	**972**	**1 409**	**657**	**864**	**522**	**587**
Hyperscale	84	129	146	342	427	434	574	360	432	253	269
Colocation and service provider	51	72	94	266	406	361	594	291	425	185	235
Enterprise	42	51	55	124	153	176	242	6	7	84	84

*2035 numbers serve as exploratory scenarios given the high level of uncertainty around data centre demand growth.

Simple time series plots were used to track changes in grid emissions. Spatial differences for the year 2023 were shown using a color map. Electricity use over time was plotted to show growth. A basic emissions estimate was created by multiplying the average carbon intensity by the total electricity use for the two years, 2020 and 2023. This allows a direct comparison of how demand growth interacts with grid improvements.

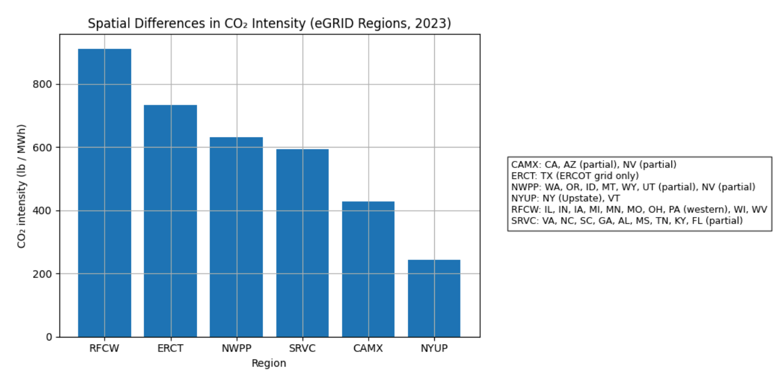
eGRID Data									
	2012	2014	2016	2018	2019	2020	2021	2022	2023
CAMX	619.9	568.6	527.9	496.5	453.2	513.5	513.7	497.4	428.5
NWPP	915.7	907	651.2	639	715.2	600	634.6	602.1	631.7
ERCT	1103.2	1142.8	1009.2	931.7	868.6	818.6	813.6	771.1	733.9
RFCW	1497.1	1380.8	1243.4	1166.1	1067.7	985	1046.1	1000.1	911.4
SRVC	862.3	856.6	805.3	743.3	675.4	623.1	639.7	623	593.4
NYUP	377.2	365.7	294.7	253.1	232.3	233.5	233.1	274.6	242.1
Energy & AI Data									
	2020	2023	2024	2030					
Electricity Co	269	361	416	946					

Table of eGRID carbon intensity values for CAMX, NWPP, ERCT, RFCW, SRVC, and NYUP from 2012 to 2023.

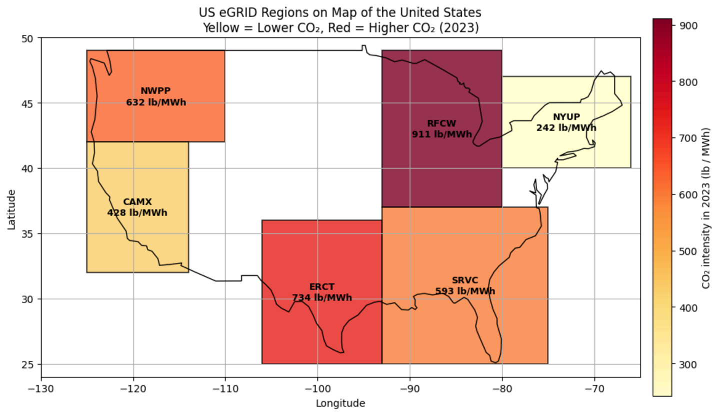
The method follows a precise sequence, grid emissions are examined across time while spatial conditions are mapped. AI electricity use is plotted and the results are combined to show how these trends interact.

Results:

Grid emissions declined from 2012 to 2023 in every region examined. CAMX and NWPP already had lower emissions in 2012 and continued to make progress while ERCT and RFCW had higher emissions but still showed steady declines. These reductions align with national trends that are associated with a decline in coal use and an increase in renewable electricity (Brown and O'Sullivan, 2020). The spatial pattern for 2023 still showed significant differences. RFCW had the highest carbon intensity whereas NYUP had the lowest. ERCT and SRVC remained in the mid-to-high range. These regions also host some of the most significant data center clusters.

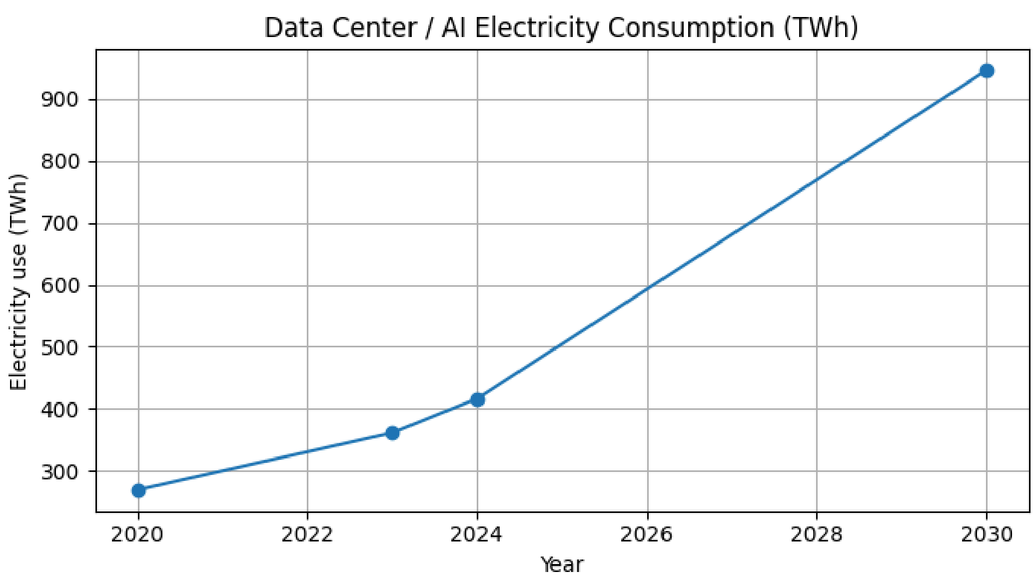


Carbon intensity values for the six selected eGRID regions in 2023.



Map of six eGRID regions in the United States in 2023. Colors show carbon intensity. Yellow marks cleaner regions and red marks higher emissions.

Electricity use from AI and data center activity skyrocketed (International Energy Agency, 2023). The rise from 269 TWh in 2020 to 361 TWh in 2023 and 416 TWh in 2024 represents substantial increases (International Energy Agency, 2023). The projection for 2030 is 946 TWh highlighting the fact that this rapid growth is much faster than the rate of change in grid emissions.

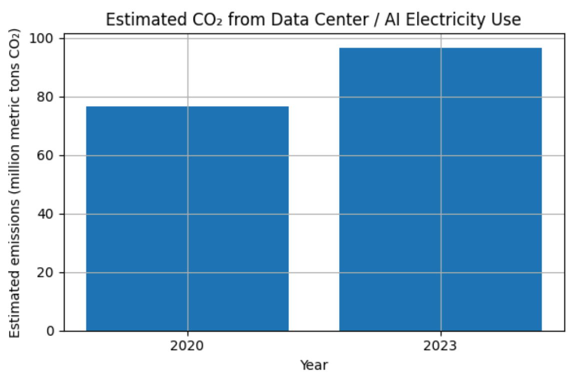


Electricity use from data center and AI workloads for 2020 to 2024 with a projection for 2030. The trend shows strong demand growth.

The combined emissions estimate clearly demonstrates this. Even though the grid was cleaner in 2023 than in 2020, total emissions from AI-related electricity use increased. Demand growth outweighed improvements in carbon intensity. The simple comparison suggests that without significant changes in siting or energy sourcing, total emissions from AI computing will continue to rise as electricity use expands.

Discussion and Conclusions:

Estimated total CO2 emissions linked to AI electricity use in 2020 and 2023. Emissions rise even though the grid becomes cleaner.



This study shows that the United States' electric grid is becoming cleaner. The trend is consistent with findings in other research on long-term energy transitions. The spatial pattern of grid emissions remains uneven, with many large data centers located in regions of mid- to high carbon intensity, raising the emissions impact of the recent growth in AI computing.

Electricity use for AI workloads has increased at a pace that exceeds the rate of grid decarbonization. This pattern matches global reports on data center growth from the International Energy Agency. It also reflects concerns raised in studies on the energy use of machine learning. The results here align with those broader findings. They demonstrate that the current direction of AI growth will increase total emissions, even in a grid that is improving over time.

The main conclusion is clear. Grid improvements are not enough to counteract the rapid rise in AI electricity demand. The placement of data centers plays a crucial role in determining emissions outcomes. Cleaner energy sourcing and careful siting decisions will be needed if total emissions are to decline. Further work could include the use of hourly marginal emissions, a wider set of regions, and detailed modeling of future growth under different policy conditions.

Statement of AI Usage:

AI tools were utilized to assist with generating the map figure and python code generation to showcase additional key points in trends. AI support was also used for writing code for data cleaning and plotting tasks. All data selection, analysis, and interpretation were completed by Krish Garg.

References:

Brown, T., & O’Sullivan, F. (2020). Decarbonization of the U.S. electricity sector. Energy Policy, 143, 111 to 119.

International Energy Agency. (2023). Data centres and data transmission networks – Analysis. https://www.iea.org/reports/data-centres-and-data-transmission-networks

International Energy Agency. (2024). Electricity 2024. https://www.iea.org/reports/electricity-2024

Strubell, E., Ganesh, A., & McCallum, A. (2019). Energy and policy considerations for deep learning in NLP. Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics, 3645 to 3650.

U.S. Department of Energy. (2023). Data center energy and water consumption report.

U.S. Environmental Protection Agency. (2023). eGRID2023. https://www.epa.gov/egrid