CIRRUS NEXUS

THE CLEANEST DATA CENTER REGIONS

In the United States and Select European Countries in June 2022

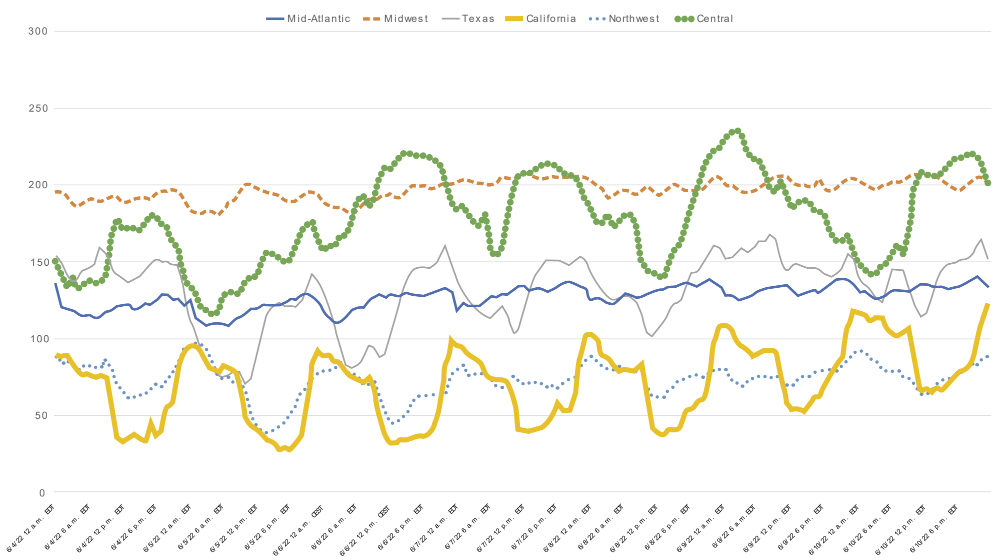
Report Key Findings

1. CARBON ARBITRATION – The actual cloud costs of running workloads is relatively stable on a daily basis, but carbon intensities can fluctuate greatly. Therefore, companies have opportunities to reduce their cloud carbon emissions by tracking their workloads to these daily patterns, without materially affecting their total cloud spend.

2. ENERGY STORAGE – We need investment in energy storage technology, so we can better take advantage of times when we have strong solar, wind, and water power. Renewable energy is inconsistent, as it's subject to the patterns of nature, and shortfalls are usually offset by fossil fuels.

3. TRUECOST OF CLOUD WORKLOADS – Running your cloud workloads can be up to 2-7% more than the published cloud costs in Europe and 2-9% in the United States, once you factor in the cost of carbon.

Carbon Intensities by Region – 7 Days in USA (Eastern Daylight Time)



SUMMARY

- California and the Northwest were the cleanest data center regions, and fluctuated mostly due to changes in renewable energy production.
  - In California, solar energy peaked at 57% of energy production during the day, with natural gas predominantly making up the shortfalls. Its carbon intensity increased as the week continued, as wind power production fell, which was partially offset by increased net power transmission received from the Northwest.
  - In the Northwest, hydro comprised over 50% of energy production and remained fairly steady through the week.
- The Midwest was persistently dirty because its top two sources of energy production were coal (39%) and natural gas (36%). Natural gas production picked up later in the week to make up for shortfalls from wind power.
- Texas fell in the middle for carbon intensities because its top two energy sources were natural gas (43%) and wind (24%). It also had a decent base in other renewable energy, with a mix of solar and nuclear totaling to 15% of energy production.

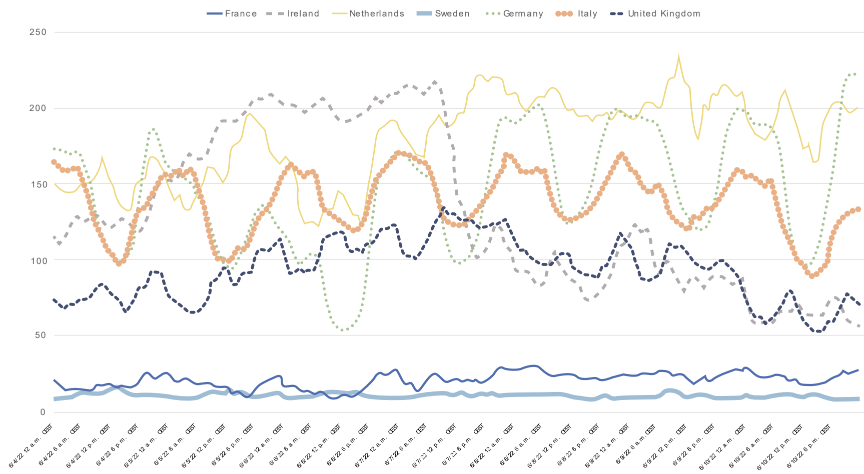
WHAT'S STOPPING EVERYONE FROM MOVING THEIR WORKLOADS TO CALIFORNIA AND THE NORTHWEST?

1. COST – California was the most expensive data center region, with workloads costing on average 3-10% more than other regions in the U.S.

2. LOCATION PREFERENCE AND CAPACITY – The Northwest, although competitively priced, may not have been in the decision set for companies who have operations in other parts of the country. Generally, companies like to place their workloads in regions closer to their operations. Also, if they have on-premise resources located in other parts of the country, they may face increased latency. Finally, often, service and capacity may not be available in every region for every customer.

3. SNAPSHOT IN TIME – "Green" data center regions don't always stay that way, and can change at different moments in time. During this week, Texas at certain times had similar carbon intensity to that of California and the Northwest.

Carbon Intensities by Region – 7 Days in Europe (Central European Summer Time)



SUMMARY

- France and Sweden were the cleanest data center regions during this snapshot in time because they're mostly powered by low-carbon energy sources. On average, France generated 66% of its electricity from nuclear, and Sweden was 32% nuclear, 50% hydro, and 15% wind.
- Ireland's carbon emissions fluctuated dramatically during this time due to variations in wind power throughout the week. Over a 2-day period, wind power hovered around 10% of total production. Yet for the rest of the week, it averaged 57%. During this time, natural gas made up for the energy shortfalls and went from a typical average of 35% of total energy production to a peak of 84%. However, at the end of the week, wind power climbed to an average of 71% of total production. Ireland ended up generating excess power on the grid and was a net exporter to the U.K.
- Germany has significant solar power infrastructure, and at peak production times, solar accounted for 30-40% of total energy. However, coal frequently made up for the shortfalls in energy production at night, resulting in predictable spikes in carbon intensity. Wind power fluctuated during this week, ranging from 4-52% of total energy production, and peaked on Monday, June 6, which was Germany's cleanest energy day.

WHAT'S STOPPING EVERYONE FROM MOVING THEIR WORKLOADS TO FRANCE AND SWEDEN?

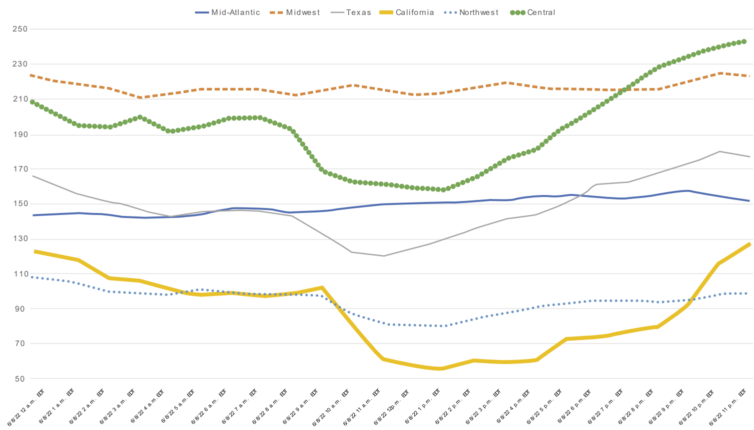
1. COST – France was one of the more expensive data center regions, with workloads costing on average 5% more than Ireland, one of the cheapest data center regions in Europe.
    - As demand potentially increases for cleaner data center regions, and supply for these cleaner regions is constricted in the short to medium term, costs may be expected to increase further.

2. DISTANCE – Sweden, although competitively priced, is located further north from many population centers, which could result in increased latency. On average, accessing systems in Sweden would result in an additional 30-40 milliseconds of latency compared to more mainland European data centers.

3. COMPLIANCE – Certain data cannot be moved across borders, due to regulatory requirements such as the EU's GDPR and Germany's BDSG.

4. SNAPSHOT IN TIME – "Green" data center regions don't always stay that way and can experience significant fluctuations in carbon intensities due to frequently changing energy demands and sources. Ireland went from middle of the road, then to the dirtiest, and finally to the third cleanest data center region, all within the same week.

Carbon Intensities by Region – 24 Hrs in USA (Eastern Daylight Time)



SUMMARY

In the U.S., most regions were steady in their carbon intensities on Wednesday, June 8, but there was significant variation in Texas, California, and the Central region due to their renewable energy resources.

- Texas had higher wind energy production in the early morning, accounting for up to 35% of total energy production. It also saw solar energy production pick up during the day, peaking at 12% around noon. Natural gas production dropped during this time to 29%.
- California's solar panels provided 54% of total energy production at its peak on this day. Similarly, wind and hydro production increased in the early morning to peaks of 26% and 18%, respectively. This helped drive down natural gas energy needs from a high of 51% down to 21% of total energy production.
- The Central region reduced its coal power use during the day from 52% of total energy production to 33%, as wind power picked up and natural gas energy production increased. However, wind production dropped significantly during the end of the day, which pushed up coal and natural gas energy usage.

CARBON'S IMPACT ON WHERE TO RUN CLOUD WORKLOADS

Cost plus Carbon Cost per hour, % difference from base cost, 24 hr analysis

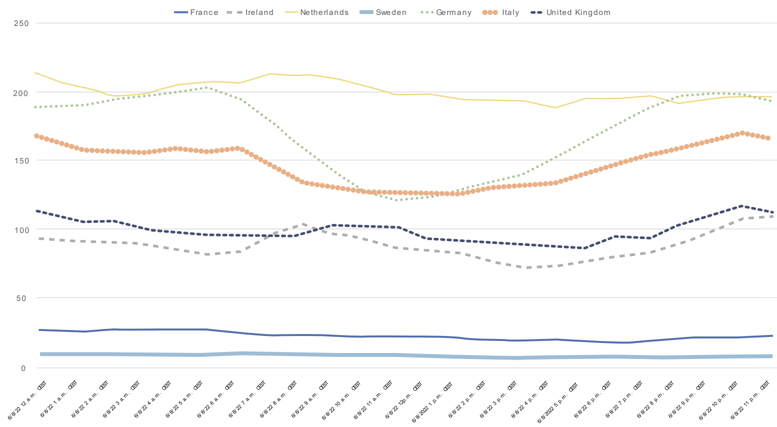
United States Regions						
Carbon Cost:	$50 per ton		$100 per ton		$200 per ton	
	Min	Max	Min	Max	Min	Max
Mid-Atlantic	0.54%	1.68%	1.08%	3.31%	2.14%	6.41%
Midwest	0.80%	2.34%	1.58%	4.58%	3.11%	8.76%
Texas	0.51%	1.46%	1.02%	2.88%	2.01%	5.59%
California	0.34%	0.61%	0.67%	1.22%	1.34%	2.41%
Northwest	0.38%	1.01%	0.75%	1.99%	1.49%	3.91%
Central	0.69%	1.85%	1.37%	3.63%	2.70%	7.01%

Cost plus Carbon Cost per hour, % difference from base cost, 7 day analysis

United States Regions						
Carbon Cost:	$50 per ton		$100 per ton		$200 per ton	
	Min	Max	Min	Max	Min	Max
Mid-Atlantic	0.49%	1.68%	0.97%	3.31%	1.92%	6.41%
Midwest	0.75%	2.40%	1.50%	4.68%	2.95%	8.94%
Texas	0.32%	1.72%	0.64%	3.38%	1.27%	6.53%
California	0.16%	0.88%	0.32%	1.75%	0.65%	3.43%
Northwest	0.22%	1.07%	0.44%	2.12%	0.89%	4.14%
Central	0.48%	2.44%	0.96%	4.76%	1.91%	9.09%

Depending on the cost that you assign to carbon, the TrueCost (Actual Cost + Carbon Cost) of running your workloads in the U.S. can be up to 2-9% more than the published cloud costs during a 24-hour period. There are similar added costs over a 7-day period. It varies widely based on data center regions.

Carbon Intensities by Region – 24 Hrs in Europe (Central European Summer Time)



SUMMARY

Most regions were steady in their carbon intensities throughout Wednesday, June 8, but Germany's and Italy's carbon intensities dropped due to their heavy solar infrastructure.

- As solar power climbed to 41% of total power generation in Germany, the country was able to run on relatively cleaner energy. During the evening, Germany's solar power was primarily offset by coal.
- Similarly, solar power peaked at 27% in Italy during the day and was offset by natural gas in the evening.

CARBON'S IMPACT ON WHERE TO RUN CLOUD WORKLOADS

Cost plus Carbon Cost per hour, % difference from base cost, 24 hr analysis

European Regions						
Carbon Cost:	$50 per ton		$100 per ton		$200 per ton	
	Min	Max	Min	Max	Min	Max
France	0.08%	0.21%	0.17%	0.42%	0.33%	0.84%
Ireland	0.30%	0.79%	0.59%	1.56%	1.17%	3.08%
Netherlands	0.68%	1.91%	1.35%	3.74%	2.66%	7.21%
Sweden	0.03%	0.10%	0.06%	0.19%	0.13%	0.39%
Germany	0.60%	1.45%	1.20%	2.86%	2.37%	5.55%
Italy	0.51%	1.32%	1.01%	2.60%	1.99%	5.06%
United Kingdom	0.33%	0.90%	0.66%	1.78%	1.31%	3.49%

Cost plus Carbon Cost per hour, % difference from base cost, 7 day analysis

European Regions						
Carbon Cost:	$50 per ton		$100 per ton		$200 per ton	
	Min	Max	Min	Max	Min	Max
France	0.03%	0.21%	0.07%	0.43%	0.13%	0.85%
Ireland	0.20%	1.97%	0.41%	3.87%	0.81%	7.45%
Netherlands	0.42%	2.17%	0.84%	4.24%	1.67%	8.13%
Sweden	0.03%	0.12%	0.06%	0.25%	0.12%	0.50%
Germany	0.28%	1.45%	0.55%	2.86%	1.10%	5.55%
Italy	0.34%	1.32%	0.67%	2.60%	1.33%	5.06%
United Kingdom	0.20%	1.22%	0.40%	2.42%	0.80%	4.73%

Depending on the cost that you assign to carbon, the TrueCost (Actual Cost + Carbon Cost) of running your workloads in Europe can be up to 2-7% more than the published cloud costs. There are similar added costs over a 7-day period. It varies widely based on data center regions.

Report Methodology

We analyzed power grid regions that have data centers operated by the major cloud service providers in the U.S. and selected European countries.

We calculated energy consumption from production and net transmission data and converted energy consumption by hour to direct carbon emissions, based on data and guidelines from the IPCC, US EIA, and UK BEIS.

We tracked cloud environment prices at the top three public cloud service providers in early June 2022 and energy usage and breakdown in top data center regions from 6/4/22 – 6/10/22, based on data from US EIA, PJM, ENTSOE, and GridWatch.

We assumed a computing workload consisting of a typical Linux 4 core general purpose server running with a single HDD disk attached and a separate 4 core MySQL database server, and variable usage:

- 80% usage rate from Mon – Fri 2-4pm.
- 50% usage rate from Mon – Fri 10am-2pm and 4pm-8pm.
- 20% usage rate from Mon-Fri 8am-10am and 8pm-10pm.
- <5% usage rate at all other times.

We determined the electricity consumed by these workloads based on manufacturer product spec sheets and product documentation.