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Generational growth

AI/data centers' global power surge and the Sustainability impact

For years, power demand from data centers was flat despite a near tripling in the data workload. Now with the pace of power efficiencies decelerating and AI demand building, our updated analysis implies data center power demand is poised to grow 160% by the end of the decade, which should drive a significant acceleration to a level of electricity growth in the US and Europe not seen in a generation. We believe this should enhance investment opportunities across the power supply chain benefiting from Green Capex, volume growth and innovation. We continue to see a myriad of potential benefits from AI towards advancing Sustainable goals; our expectations for a more than doubling of data center carbon dioxide emissions in 2030 vs. 2022 will likely focus Sustainable investors on measuring how AI's benefits can offset the expected increase in data center-related emissions.

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AI/data centers' impact on power, emissions, Sustainable Investing, stocks: Six key takeaways

We believe data demand — driven in part by AI and in part from deceleration in efficiency gains — will catalyze generational growth in global power demand. Our updated analysis (discussed within) suggests a 160% increase in data center power demand by decade end, with data centers rising to 3%-4% from 1%-2% of overall global power demand (to 8% from 3% in the US). We continue to see a myriad of potential benefits from AI towards advancing Sustainable goals and believe semiconductors' contribution to avoided emissions and decarbonization, infrastructure and clean water goals warrant consideration for thematic investment. We see favorable tailwinds for the Green Capex-exposed stocks. At the same time, our analysis suggests a more than doubling in data center carbon dioxide emissions in 2030 vs. 2022 (the increase representing about 0.6% of energy emissions), which will likely focus Sustainable investors on measuring how AI's benefits can offset the expected increase in data center emissions.

What's inside. In our report we update our outlook for data center power demand/emissions (initially in our Greenablers: The critical role of Semiconductors towards a sustainable future report), discuss implications for opportunities and risks across the supply chain, estimate what value and equivalent innovations would be needed to offset the expected emissions increase, and update our outlook for data center avoided emissions.

Six key takeaways from our analysis

(1) Power demand

Data center power demand **likely to rise 160% by the end of the decade** vs. 2023 from **1%-2% to 3%-4% of overall global power demand by 2030**. If all of the projected data center electricity demand growth was concentrated into a new country, it would be among the top 10 power consuming countries. Our US Utilities Research team sees **US power demand growth accelerating to a 2.7% 5-year CAGR by 2030 vs. 0% for the past 10 years**, with data centers driving 0.9% CAGR increase and representing **8% of US power demand by 2030** (vs. 3% in 2022). In Europe, our Utilities Research team sees **EU-27 power demand accelerating to a 3.7% 5-year CAGR by 2030 from 0%** for the past decade.

(2) Emissions

Data center power demand growth is on track to drive a **more than 100% increase (about 215-220 mn tons) in data center carbon dioxide emissions** by 2030 vs. 2022 per our updated analysis, the increase representing about 0.6% of global energy emissions. This assumes data centers fund renewable PPAs for around 30% of total needs in the coming years and that natural gas fills the bulk of power generation on the margin.

(3) Data center efficiencies

Data centers ex-AI have continued to become less power intensive, but the pace of efficiency gains appears to have considerably slowed. Relative to 2015 baseline, we see **avoided carbon dioxide emissions from data centers of 1,000-2,000 million tons in 2030** in our updated analysis. Notably, much of the avoided emissions were based on 2015-19 efficiency gains. Demand growth is currently more than offsetting power efficiency, driving higher expected emissions. A re-acceleration of efficiencies to levels greater than our base case could mitigate the emissions growth we forecast, and we note corporate optimism that this can be done.

(4) Valuing AI's Sustainable benefits & costs

We continue to see **potential AI benefits via speeding up drug/vaccine/therapeutic discoveries, improving crop yields, and increasing energy efficiency** among other potential innovations, though with uncertainty on the magnitude and timing. The AI power surge and emissions increase is likely to prompt greater interest among Sustainable investors to quantify AI value added (similar to avoided emissions frameworks) vs. the rising emissions from AI power consumption. We estimate a **present value of about $125-$140 bn social cost from the data center carbon dioxide emissions growth we forecast** (AI + non-AI) in 2024-30, which could act as a benchmark for measuring offsetting benefits.

(5) Sustainable Investing outlook implications

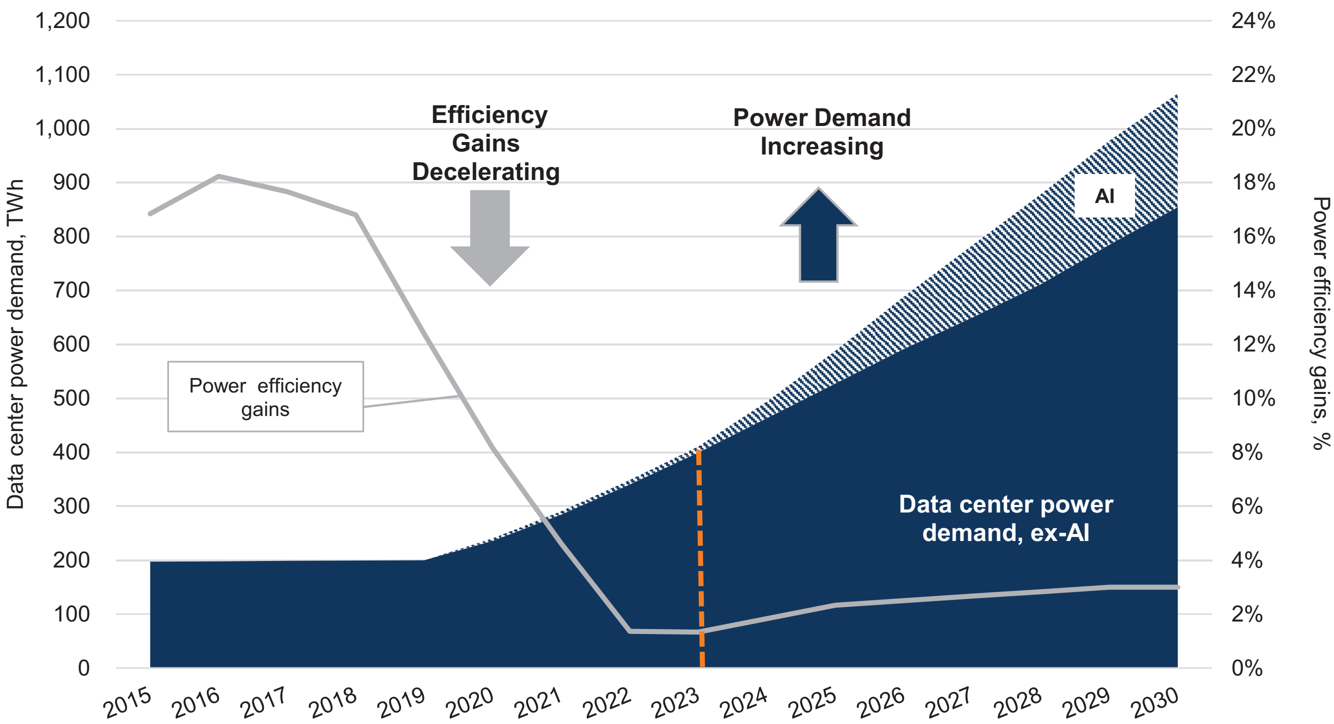
AI power demand growth and rising data center emissions add to broader Sustainable Investing uncertainties in 2024 (interest rates, elections, actual vs. needed investment towards sustainable goals) that we believe support investments in companies that benefit simultaneously from investment and underinvestment towards Decarbonization and Adaptation. Our AI and data center analysis supports **owning stocks levered to overlapping themes among decarbonization, Adaptation, Circular Economy, Biodiversity and Affordability/Accessibility**.

(6) Stocks

We see potential beneficiaries among **Utilities** driven by volume growth (complementing investment towards Adaptation/grid hardening and fleet transformation towards renewables), **renewables providers** as we see acceleration in renewable power purchase agreements (PPAs) by technology companies, **energy efficiency enablers** and **infrastructure contractors**.

Exhibit 1: As efficiency gains have decelerated, data demand growth is driving a surge in data center power use, with an AI kicker on the way

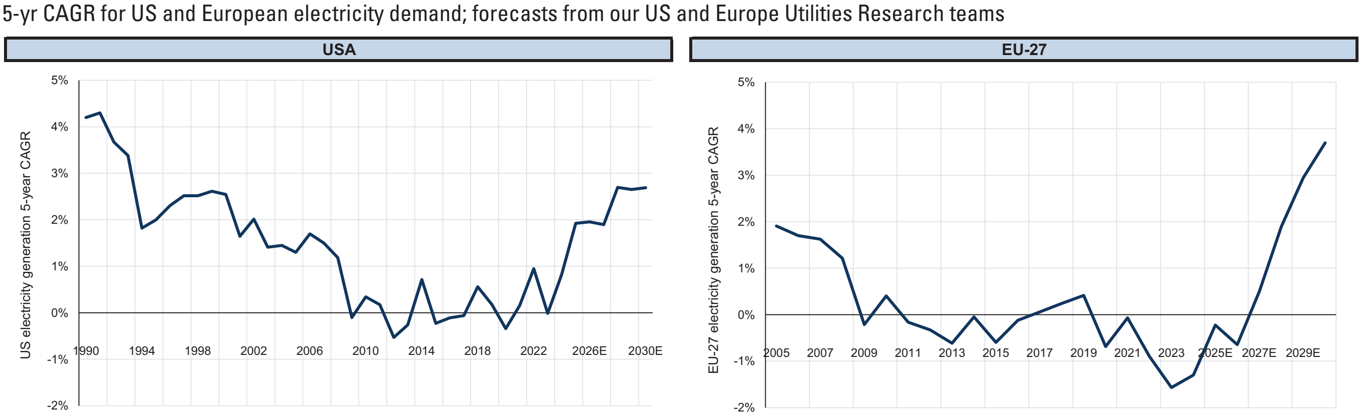
Data center electricity consumption, TWh (LHS) and power efficiency gains ex-AI, % (RHS)



Source: Masanet et al. (2020), IEA, Cisco, Goldman Sachs Global Investment Research

Exhibit 2: Generational Growth: Our Utilities Research teams now expect USA and EU-27 electricity consumption accelerating through the end of the decade to levels not seen in 20+ years

5-yr CAGR for US and European electricity demand; forecasts from our US and Europe Utilities Research teams

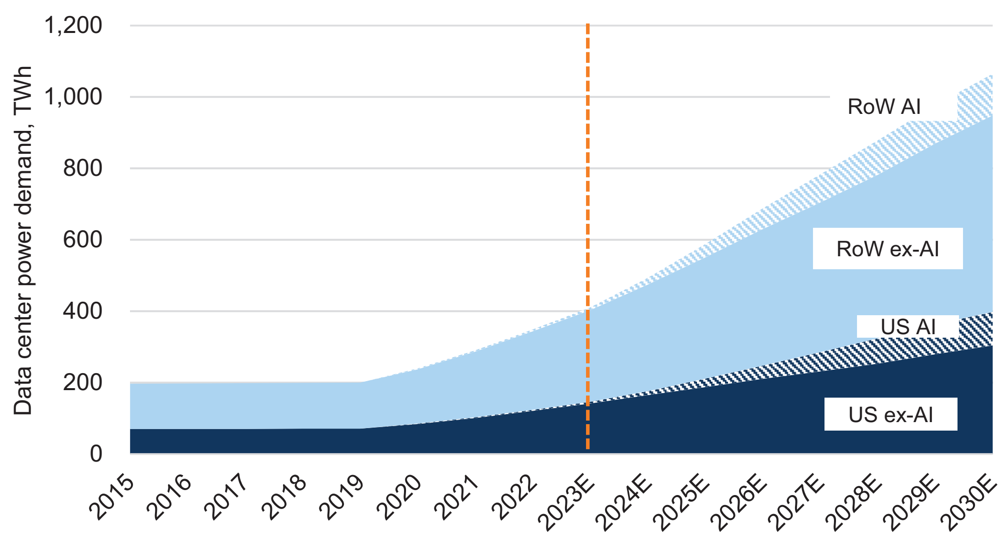


Source: EIA, EMBER, Goldman Sachs Global Investment Research

Quantifying the AI and broader data center power surge

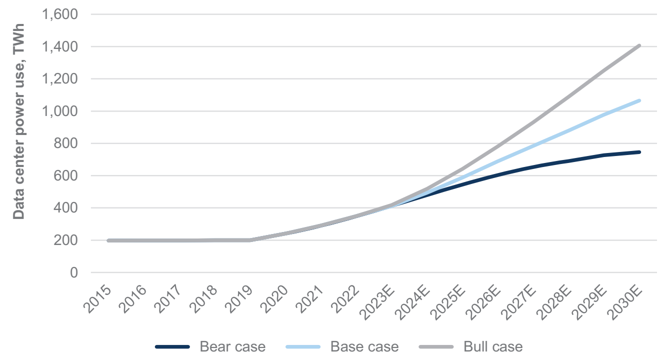
The combination of AI, ex-AI increases in data demand and a material slowdown in power efficiency gains is making data centers a critical driver of accelerating global and US electricity demand growth. We assume data center power demand excluding cryptocurrency will grow by 160% in 2030 vs. 2023 levels (bear/bull range of 80%-240% growth), representing an increase of about 650 TWh by 2030 in our base case (330/1,000 TWh in our bear/bull cases). Our US Utilities Research team estimates data centers alone will contribute a 0.9% CAGR to overall US power demand, bringing the total expected CAGR to 2.4% through 2030. We see data centers adding a 0.3% CAGR to overall global power demand. Our base case implies data center power demand moves from 1%-2% of overall global power demand to 3%-4% by 2030. The increase in the US is even greater — from 3% to 8%. Our estimates for overall data center power demand are above IEA forecasts (2026), and our outlook for AI to represent about 19% of data center power demand in 2028 is above recent corporate forecast.

Exhibit 5: After being flat for 2015-19, we have seen data center power demand accelerate in 2021-23 and expect a 160% increase through the rest of the decade
Global data center electricity consumption, TWh; includes AI and excludes cryptocurrency



Source: Masanet et al. (2020), Cisco, IEA, Goldman Sachs Global Investment Research

Exhibit 6: We see 2030 power use from data centers 1.8x-3.4x 2023 levels in our bear/bull case
Electricity demand from data centers in TWh, base case, bear case and bull case



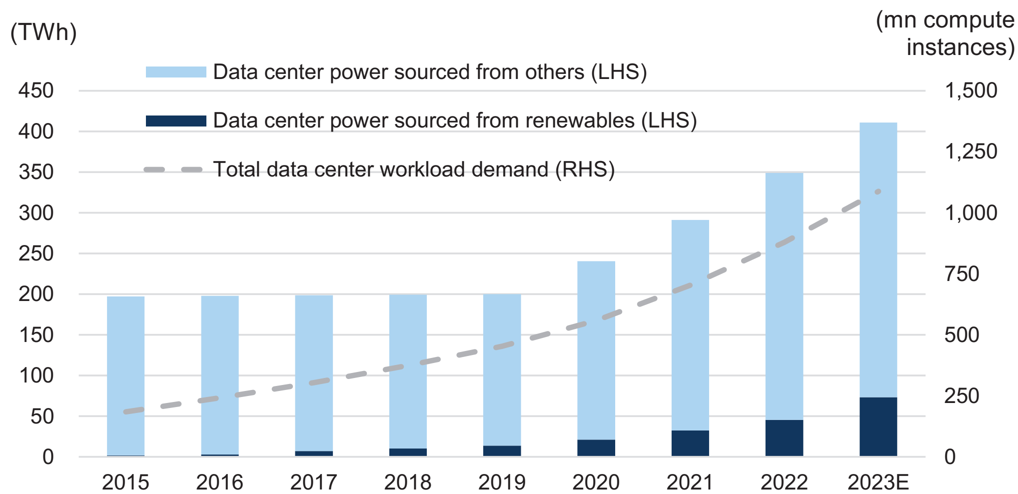
Source: Masanet et. al (2020), Cisco, IEA, Goldman Sachs Global Investment Research

Data demand has been growing, but until recently power demand from data centers was flattish. Between 2015 and 2019, data center workload demand nearly tripled while data center power demand was relatively flat. There were two main drivers of this:

- Power consumption efficiency gains (i.e., pace of lower power intensity) within cloud and hyperscale data centers. Annual efficiency gains averaged about 15%.
- Mix shift towards cloud and hyperscale data centers which have materially lower power consumption intensity than traditional data centers. By 2020 more than 90% of data center workload demand was at cloud/hyperscale centers.

We estimate in 2020 data center power demand was about 240 TWh, based on data from the IEA, Cisco and academic sources.

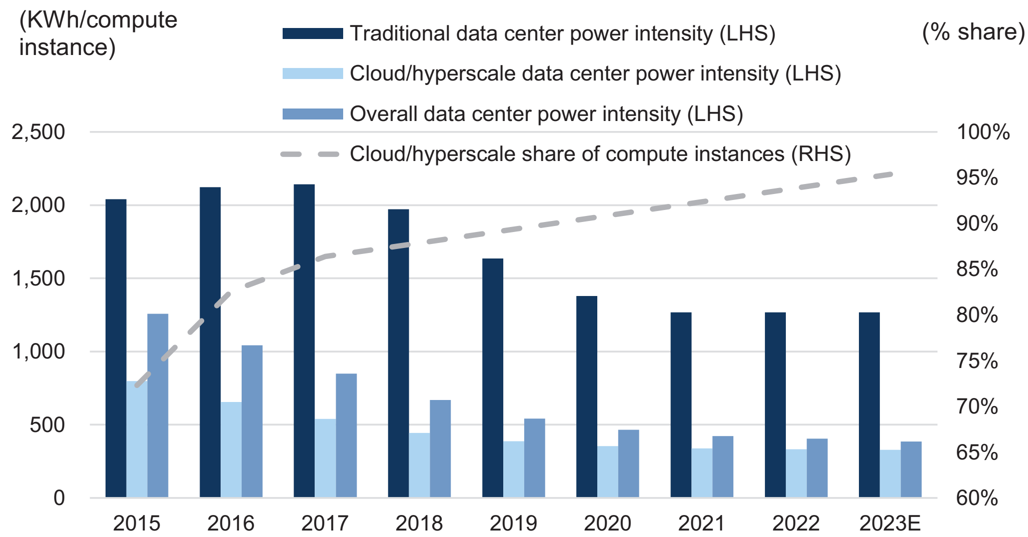
Exhibit 7: Data center workload demand nearly tripled between 2015-2019 but electricity consumption from data centers was flat
Data center workload demand (RHS) in million compute instances; data center power demand (LHS) in TWh



Source: Masanet eet al. (2020), Cisco, IEA, Goldman Sachs Global Investment Research

However, in the past three years, power consumption from data centers has been on the rise. With much of the mix shift already done, the gains from the shift to cloud/hyperscale have narrowed. Additionally, we have seen efficiency gains appear to wane within cloud/hyperscale data centers (reported data to calculate efficiencies is not consistently available annually and as such for some historical years are estimated or implied). The IEA estimates 2022 data center power consumption was about 350 TWh, excluding contribution from cryptocurrency; all else equal this implies cloud/hyperscale annual efficiency gains decelerated to about 1%-2% in 2020-22.

Exhibit 8: Data center efficiency gains and the shift to cloud/hyperscale have been critical drivers of the moderate increase in data center power demand, but decelerating efficiency gains have helped to drive a pickup in power demand from data centers in recent years
Data center power intensity (LHS) in KWh per compute instance; share of cloud/hyperscale data centers (RHS) as % of workload



Source: Masanet et al. (2020), Cisco, IEA, Goldman Sachs Global Investment Research

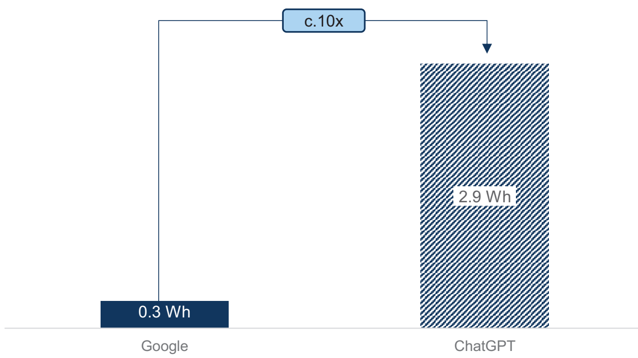
Three key assumptions will help drive data center power demand forecast.

- Data consumption outlook — both AI and non-AI
- Power efficiency gains
- Potential infrastructure constraints

AI to accelerate power demand growth

We assume power demand from AI rises about 200 TWh in 2024-30 (bear/bull case of 110-330 TWh), with AI representing about 20% of overall data center power demand by 2030 in our base case. We see a wide range in our bear/bull scenario driven by uncertainty over demand and power efficiency. As demand for AI training grows in the medium term and for inference longer term, we see demand growth well exceeding the efficiency improvements that are leading to meaningful reductions in high power AI server power intensity. We note that a ChatGPT search consumes around 6x-10x the power as a traditional Google search (see Exhibit 9).

Exhibit 9: ChatGPT queries are 6x-10x as power intensive as traditional Google searches
Power consumption per query/search (Wh)

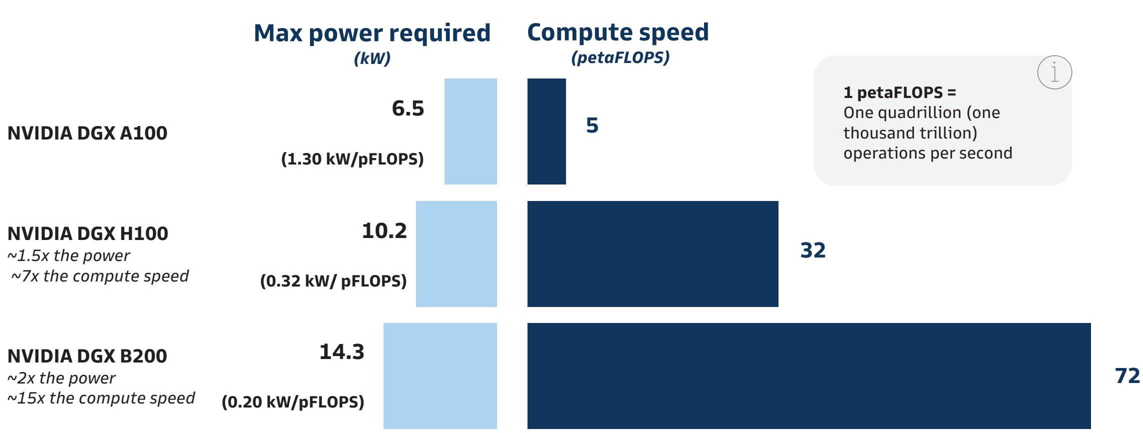


Source: Google, SemiAnalysis

We have seen new AI innovations increase both computing speed and max power consumption per server but increase computing speed at a much greater pace, representing meaningful reduction in power intensity. As demand for GPUs grows, there is still notable company-projected intensity reductions. As an example of how innovations have reduced power intensity per server but increased overall power per server:

- The NVIDIA DGX A100 system is listed to net 5 petaFLOPS and consuming 6.5 kW max, or 1.30 kW per pFLOPS.
- The more recent NVIDIA DGX H100 system is listed at 32 petaFLOPS and consuming 10.2 kW max, or 0.32 kW per pFLOPS.
- The new generation NVIDIA DGX B200 system using the new Blackwell chips is listed to net 72 petaFLOPS (training) and consuming 14.3 kW max, or 0.20 kW per pFLOPS.

Exhibit 10: We have seen new AI innovations increase max power consumption per server but increase computing speed per server by an even greater level, representing meaningful reduction in power intensity
Recent evolution of NVIDIA server system specifications are indicative of increasing max power per server but with lower power intensity relative tocomputing speed (for training)

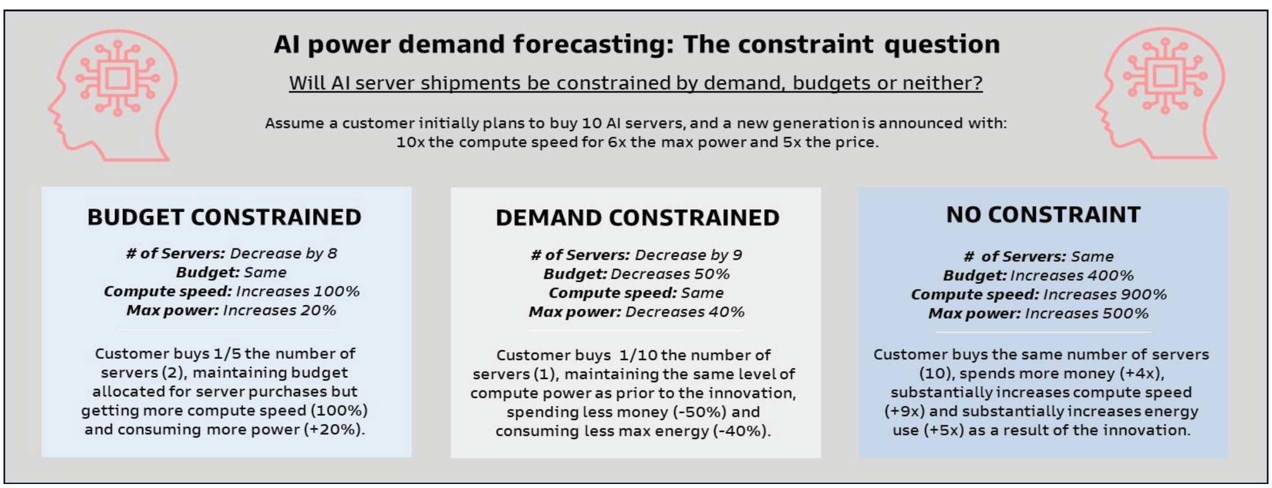


Source: NVIDIA, Goldman Sachs Global Investment Research

Our global TMT team expects AI server units shipped to grow at a 76% CAGR in 2024-26, representing a 50% CAGR in server revenues; whether demand, budgets or neither is the constraint to growth is critical for energy use forecasting. A key question impacting compute demand is whether that demand is pent-up (ie available new servers will be bought regardless of budget), not pent-up and constrained by demand itself, or constrained by customer budgets. In other words, will customers buy equal amounts of the more powerful servers as they would the less powerful ones? If in a scenario in which a customer initially desires to buy 10 AI servers, and a new generation is announced with 10x the compute speed for 5x the price, will the customer:

1. Buy the same number of servers (10), spend more money (5x) and substantially increase its compute speed as a result of the innovation (10x)? This would represent no constraints (i.e., unlimited budgets, so demand dictated by available supply).
2. Buy 1/10 the number of servers (1), maintaining the same level of compute power as prior to the innovation and spending less money (0.5x)? This would represent demand as the constraint.
3. Buy 1/5 the number of servers (2), thereby maintaining budget allocated for server purchases but getting a greater compute speed (2x)? This would represent budget as the constraint.

Exhibit 11: Extent of pent-up demand for AI server supply and voraciousness of technology capex budgets will be critical for pace of AI power consumption
Indicative scenario analysis of how demand vs. budget constraints could impact AI compute speed and power use



Assumes power generation, transmission and interconnection are not a constraint for indicative purposes

Source: Goldman Sachs Global Investment Research

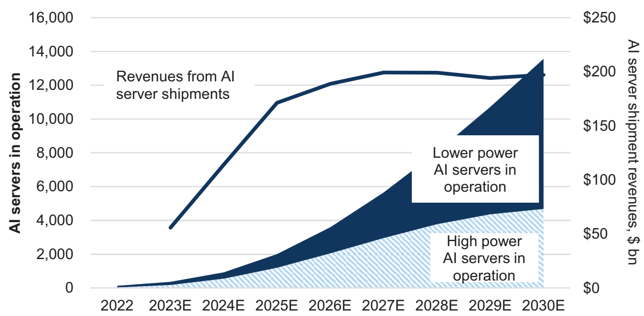
Confidence in the above question is key to whether forecasting methodology should be weighted towards server-based (requiring nuance given varied and dynamic power consumption intensity and compute intensity) vs. demand based (forecasting compute power and power intensity per unit of compute power). New generation AI servers consume more power and provide more compute speed, even as the power intensity has fallen meaningfully. There could be meaningful upside to our base case if appetite for purchase and utilization of servers is unconstrained. There could be downside to our base case if power efficiency is higher than expected or if power/compute speed efficiencies lead to fewer servers purchased than expected. We note corporate optimism that AI innovations can drive significant efficiencies to ultimately mitigate power demand and emissions growth.

We have applied both a server supply driven forecast and a compute speed demand driven forecast, with a heavier weight applied towards the supply-driven methodology.

- On the **server supply-driven side**, we apply our global Technology team's forecast for server shipments per year mentioned above, divided among high energy vs. low energy servers. We assume server replacement every 5 years. Our TMT team sees a sharp increase in high power servers (greater electricity consumption per server, higher ASP) increasing sharply in the next few years to meet demand for AI training, while the team sees greater weighting of growth from lower power servers (lower electricity consumption per server, lower ASP) towards the back of the decade as AI demand weighting shifts more towards inference. We assume 5%-8% annual power efficiency gains per year to reflect expected future server innovation — relative to demand-based energy intensities where saw higher annual efficiencies early in life cycle, we assume slower pace in a supply-based approach to reflect timing of adoption. The result is falling power intensity per computing speed and sharp increases in overall power demand due to the growth in new servers with higher weighting within higher power servers towards the newer generation that as mentioned have lower power intensity but higher power consumption per server.
- On the **demand-driven side**, we use our China Media, Internet & Telecom team's AI compute power forecast to drive global AI compute demand outlook. We assume power efficiency gains of 8%-15% annually in our base case through the end of the decade — this reflects similar efficiency gains as seen ex-AI in 2015-20.

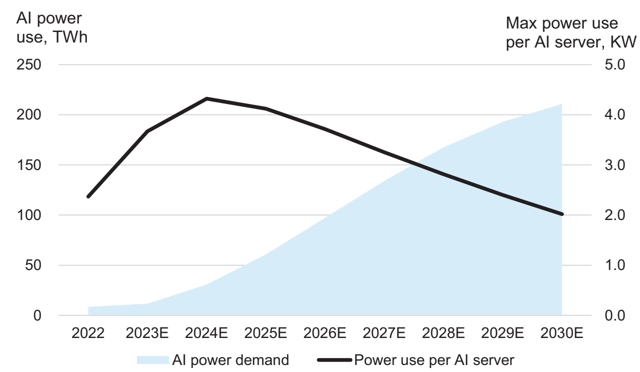
Together, this implies sharp increase in electricity use from AI, even as revenues from servers shipped are implied flattish in 2027-30. Our global TMT team's server shipment and ASP forecasts imply flattish revenues in 2027-30, driven by greater weighting towards lower power we see a greater mix shift towards lower cost lower power servers within the mix, in addition to expectations for ASP declines. However, with the mix shift and ASP reductions offset by increased volumes — and with the overall number of servers in operation continuing to grow, we see sharp demand growth from AI for electricity even despite expected efficiencies. Based on the framework and assumptions described above, we see AI power demand moving up by around 200 TWh in 2030 vs. 2023.

Exhibit 12: AI servers in operation expected to grow sharply through 2030 even as revenues from AI server shipments flattens in 2027-30
AI servers in operation and implied revenues from our global TMT team forecasts



Source: Goldman Sachs Global Investment Research

Exhibit 13: We see AI power demand growing rapidly even as power use per AI server falls later in the decade due to mix shift and expected efficiencies
AI power use, TWh (LHS); max power use per AI server, KW (RHS)



Source: Goldman Sachs Global Investment Research

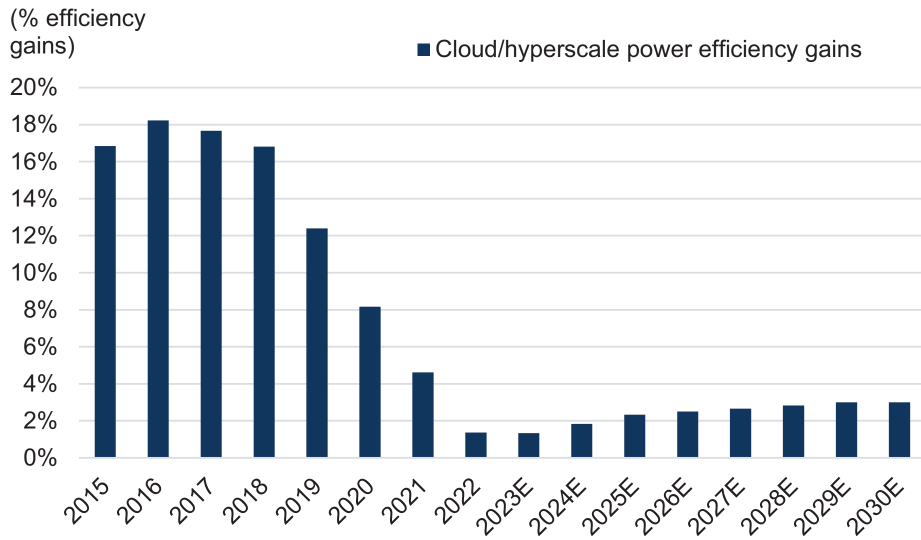
Data center power demand ex-AI

We expect continued strong growth in workload unrelated to AI. We assume double digit growth in workload compute instances with deceleration from the 20%-25% of compute instances growth seen since 2017 down to 12%-18% annual growth in 2026-30, owing to combination of maturity and expected overlap with demand via AI. A key question on ex-AI demand is whether AI modeling and user demand for AI will partially replace users' need for searches or other workload. We are broadly assuming minimal replacement — i.e., AI is largely incremental to the broader trend of data center workload demand.

Power intensity efficiency gains among cloud/hyperscale data centers have decelerated; we assume modest re-acceleration in our base case. We assume power efficiency gains — which as mentioned averaged around 15% annually in 2015-19 but decelerated to around low single digits in 2020-22 — will remain relatively low. However, we assume a slight re-acceleration to an average of 3% in our base case in 2024-30, as industry discussions suggest continued efforts towards innovation efficiencies, especially around the power intensity given the prospects for significant power needs ahead.

The implications of the efficiency gains assumption leads to a wide range between our bear and bull cases for ex-AI data center demand growth. Based on the above framework and assumptions, we see about 450 TWh of ex-AI power demand growth in 2030 vs 2023 in our base case vs. 225/650 TWh in our bear/bull cases. As we have highlighted earlier, we believe the efficiency assumption is critical driver of power demand outlook ex-AI — our bear/bull cases assume 7%/0% annual intensity reductions on average in 2024-30.

Exhibit 14: We expect power efficiency gains at cloud/hyperscale data centers to continue, but remain at a lower pace going forward relative to 2015-20
3-year rolling average % change in cloud/hyperscale KWh per compute instance



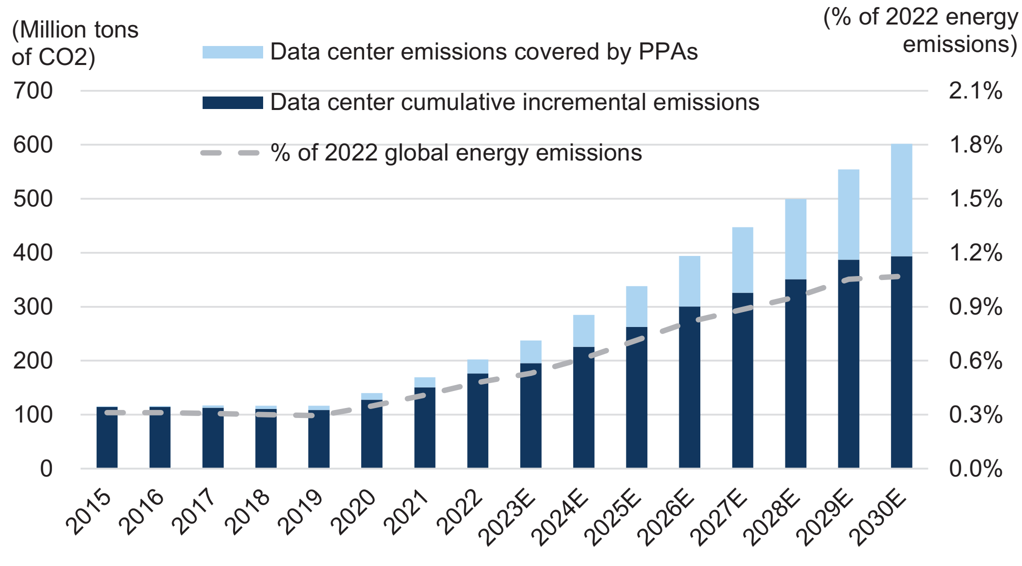
Source: Masanet et al. (2020), Cisco, IEA, Goldman Sachs Global Investment Research

Data center emissions: Potential to double by 2030

Incremental demand for power from data centers in the absence of PPAs would otherwise lead to a 150% increase in data center carbon dioxide emissions in 2030 vs. 2023 per our analysis. The sharp rise in power demand from both AI and non-AI demand at data centers is likely to lead to a sharp increase in carbon dioxide emissions. Before considering power purchase agreements (PPAs) to underwrite new renewables capacity, we would otherwise expect emissions from data centers to rise 150% by 2030 vs. 2023 levels based on increased electricity demand highlighted earlier which we assume is predominantly met with thermal power plants on the margin.

Technology companies likely to accelerate signing of renewables PPAs — a positive for renewable generation developers. Technology companies have historically been very active in both pursuing technologies that can drive energy efficiency and in signing power purchase agreements (PPAs) to underwrite development of renewable power generation. Power purchase agreements are multi-year contractual agreements to buy electricity which allow generation developers to fund capacity expansions — the resulting power generated does not necessarily directly supply the demand for the company signing the PPA. We expect PPAs for renewable energy will only accelerate given the sharp increase in AI demand. Conversations with technology companies indicate continued confidence in driving down energy intensity but less confidence in meeting absolute emissions forecasts on account of rising demand. Based on discussions with our Clean Technology team, we expect to see an increase in PPAs signed by technology companies from about 17-18 GW per year in 2020 (already a significant increase from the run rate in 2018-20 when power demand at data centers was relatively flattish) to 20-30 GW per year over the next 5 years. We estimate this level of new PPAs per year could broadly lead to technology companies covering 30% of electricity demand from renewables PPAs in 2028-30 after taking into account capacity factors that are lower relative to gas-fired plants due to intermittency.

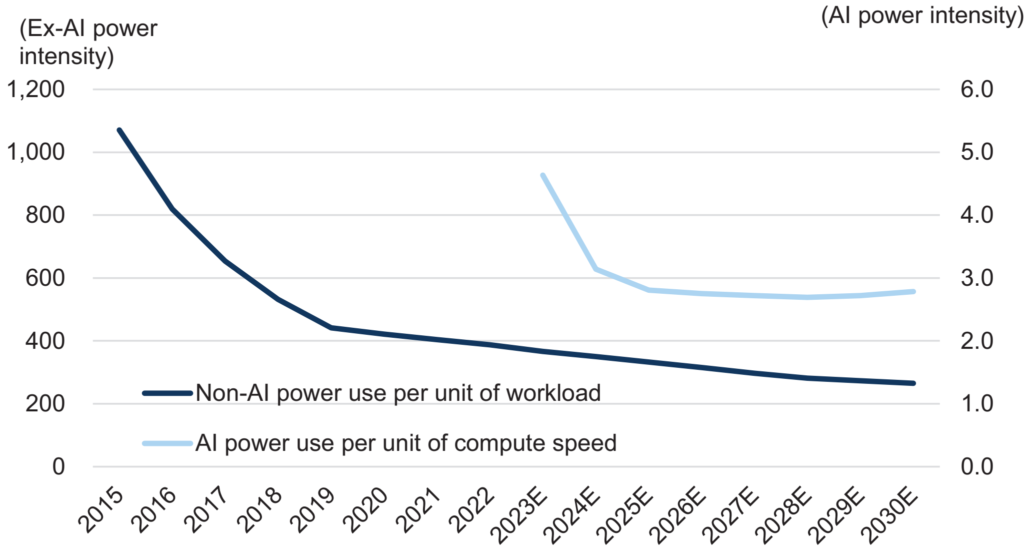
Exhibit 15: We see data center emissions doubling in 2030 vs. 2023 levels, net of impact of power purchase agreements (PPAs) from technology companies
Carbon dioxide emissions in millions of tons (LHS); percent of 2022 energy emissions (RHS)



Source: IEA, Goldman Sachs Global Investment Research

This could result in net emissions doubling by 2030, after being flattish in 2015-20. Overall we expect data center emissions to double in 2030 vs. 2023 levels, with our bear/bull case implying emissions +50%/+210%. The prospects for the rise in emissions despite power intensity improvements are likely to elevate discussions on risks around meeting Net Zero goals and potentially increase the level of investment in Green Capex required to mitigate emissions. We address this further in the forthcoming chapter. We believe this will also push both technology companies and Sustainable investors to quantify benefits of AI, and technology companies are likely to increase R&D towards further innovations that can limit energy footprint.

Exhibit 16: The emissions increase is despite efficiency gains lowering power intensity for both non-AI and AI drivers of data center power demand
Power intensity from AI and non-AI data center demand



Source: Masanet et al. (2020), IEA, Cisco, Goldman Sachs Global Investment Research

The nuclear option

Multiple factors are coalescing around greater interest in expanding nuclear generation capacity. While there remains budget and timing concerns towards further development of large-scale nuclear plants in the US, willingness to support nuclear generation expansions continues to expand. Even before nuclear being considered as a data center power demand source/solution, sentiment has been shifting more favorably for nuclear expansion as a low-carbon source of baseload generation. This sentiment improvement started with energy reliability issues in 2021 in Europe/US/China, was furthered by energy security concerns driven by Russia-Ukraine/geopolitical events, and culminated with the COP 28 communiqué calling for a tripling of nuclear capacity by 2050 (although for some countries this remains an area of contention).

Corporate investment towards emerging nuclear generation technologies receiving boost from technology companies. As more technology (and energy) companies look to rein in their carbon footprints (some based on Scope 1/2, others based on Scope 3), we have seen support for non-binding commitments to take power from emerging Small Modular Reactor (SMR) technologies increase. Oklo recently announced agreements with Equinix and Diamondback Energy. Microsoft has publicly highlighted the need for advanced nuclear technologies and investments to help speed innovation.

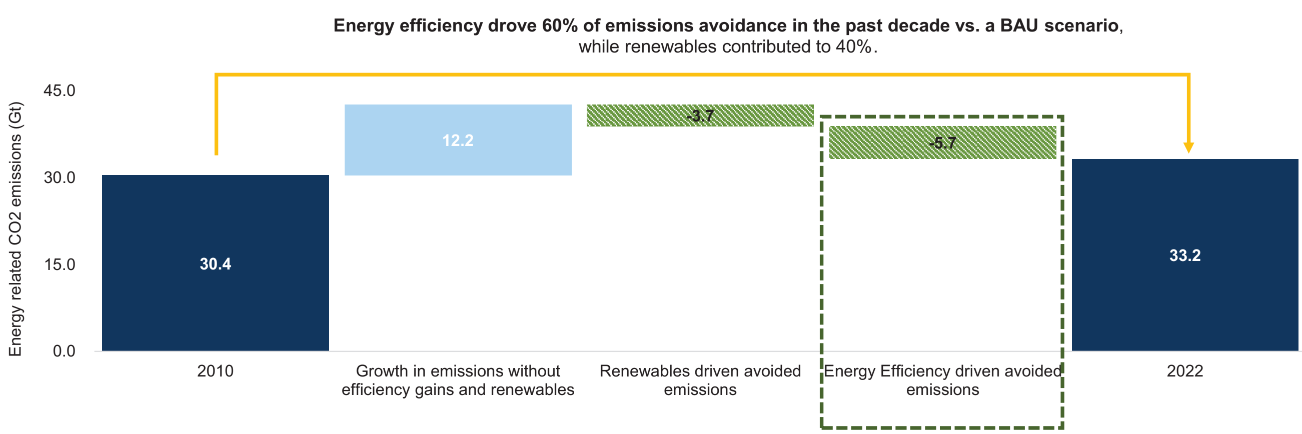
However, clarity is still needed regarding viability of SMR technologies. The Nuclear Energy Institute in September highlighted that in the US there are 2 advanced reactor licensees approved, 3 under review and 11 in pre-application phase. Based on the timing of approvals and lead time for pilots and initial project developments, we believe SMRs are more likely a potential low-carbon force to meet generation needs in the 2030s than over the medium term given time lag for technological development, government approvals and construction. We have assumed 5 GW of nuclear PPAs coming online in 2030 to reflect credit for some early success/development — the next 1-2 years will be key to guide timeline and magnitude. Traditional nuclear plants have a very high capacity factor (90%+), meaning that nuclear capacity would have >3x the energy generation per GW as a solar/wind plant. To fully offset expected data center emissions growth in 2024-30, we would need to see about 50 GW of nuclear capacity additions globally (assumes 95% capacity factor), in addition to already forecasted renewables PPAs.

Avoided emissions: Data center efficiency gains have kept electricity use, emissions from being meaningfully higher

Efficiency plays a key role in avoided emissions, historically to an even greater degree than renewables generation. Global energy related CO2 emissions increased <10% in 2010-2022, despite a ~40% expansion in real GDP. Our analysis discussed in our July 2023 report suggests energy efficiency gains across the economy have contributed to 60% of the avoided emissions globally between 2010-2022, with renewables contributing the remaining 40% (Exhibit 2 in that report). Despite their impact, sectors that enable energy efficiency ranging from Industrials, Materials to Technology are still broadly under-represented in Sustainable Investing portfolios in part because their benefits are less visible and often unmeasured. We believe sectors tied to energy efficiency can benefit from increasing investor support when assessed through the lens of avoided emissions.

Exhibit 17: Over the past decade, energy efficiency gains across sectors have played a greater role in driving avoided emissions than renewables deployment

Attribution analysis of avoided emissions from renewable energy deployment and energy efficiency gains (2010 baseline)

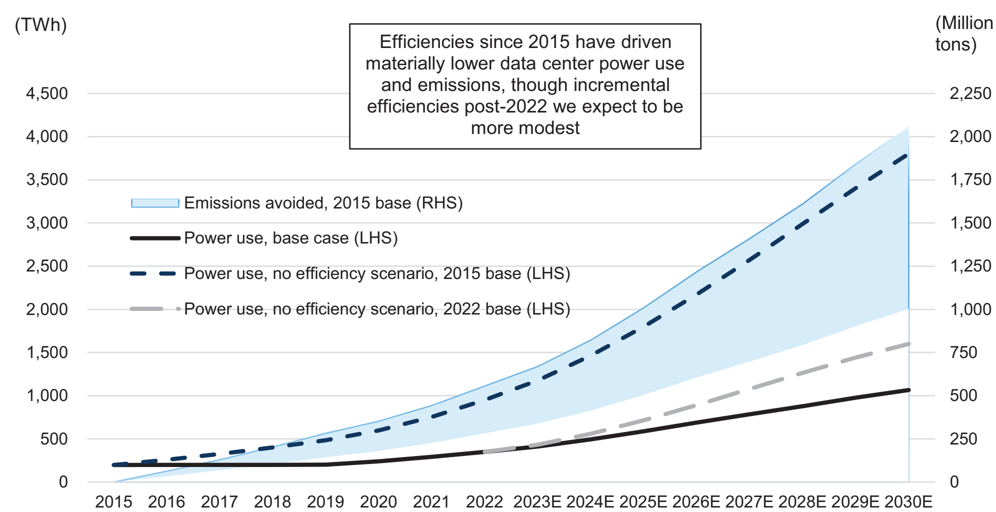


Source: IEA, World Bank, UN, Goldman Sachs Global Investment Research

Data center efficiencies have been key Greenabler of avoided emissions. As we discussed in our November 2021 Greenablers: The critical role of Semiconductors towards a sustainable future report, the sharp improvement in data center efficiency gains that led power demand to stay flattish even as data center workload almost tripled in 2015-19 represents a significant driver of emisssions. Using 2015 as a baseline year for data center power intensity (2023 for the AI component) and making no adjustments to demand, data centers have avoided more than 750 TWh of electricity demand in 2023, which we believe is likely to continue to rise going forward. Notably, however, much of the projected increase is driven by the 2015-19 efficiency gains, which appear to have waned in recent years. Nevertheless, more efficient chips/servers are reducing power intensity within AI (which may decelerate somewhat if AI sees a mix shift from training to inference over time), and we continue to expect non-AI efficiency gains going forward.

Exhibit 18: Data center efficiency gains have led to significant avoided electricity consumption and emissions, much of which was driven by efficiencies before 2022

Data center power use in our base case and assuming 2015 and 2022 (2023 for AI) as baselines for power intensity (LHS), TWh; avoided carbon dioxide emissions range assuming 2015 baseline (2023 for AI) (RHS), million tons



Source: Masanet et al. (2020), IEA, Cisco, Goldman Sachs Global Investment Research

We expect commentary from companies to highlight intensity improvements, but with less visibility regarding absolute emissions targets. As we have discussed, demand growth is leading emissions to rise despite efficiency gains and emissions intensity decreases, which is pushing technology companies to increase PPAs and pursue clean reliable energy emerging technologies to mitigate the impact on absolute emissions. We believe this could lead to greater discussion among Sustainable Investors regarding avoided emissions approaches, particularly using the attributional vs. consequential methods (i.e., whether to make adjustments for demand growth stemming from product innovation). The World Resources Institute argues the consequential approach is more comprehensive and potentially more useful for policy decisions. However, the WRI recommends the "Attributional Approach" as an interim solution if data availability is limited. Our avoided emissions analysis reflects an attributional approach. For more details, please see our July 2023 report, How quantifying Avoided Emissions can broaden the decarbonization investment universe .

What enabling value does AI/data centers need to demonstrate to offset

the rise in emissions?

Putting 215-220 mn tons of emissions into context — what would represent equivalent offsetting benefits? A 215-220 mn ton increase in carbon dioxide emissions from data centers would represent a 0.6% increase in overall energy emissions relative to 2022 levels. Before considering AI/data center enabled innovations that do not directly reduce emissions (i.e., health improvement, agricultural efficiency as examples) we highlight 4 examples of potential innovations or solutions that would individually equate to reduced carbon dioxide emissions of 215-220 mn tons.

- More efficient internal combustion engine vehicles or alternative vehicles that lower gasoline demand globally by 7%.
- Solutions that accommodate lower global electricity consumption by about 2%.
- The addition of about 50 GW of nuclear capacity assuming 95% capacity factor.
- Innovation towards aviation jet fuel efficiency or towards affordable sustainable aviation fuel that lowers consumption of traditional jet fuel by 18%.

In the absence of direct emissions reductions enabled by data centers/AI, the expected surge in data center demand and the contribution from AI/data centers to higher emissions will likely lead to a value assessment. Measuring the tradeoff of higher power consumption for enabled benefits may not be as easy as an avoided emissions analysis where avoided emissions are compared to actual emissions. In this case, the tradeoff may need to be value based — value enabled vs. cost of increased emissions. In determining the cost of emissions, the $/ton social cost is an area of debate. Notably, the US EPA after a November 2023 update to its framework applies a $190 per ton social cost of carbon dioxide emissions[1], and a September 2022 article in Nature[2] argues for a $185 per ton cost. **Using a $190 per ton social cost of carbon 215-220 million tons of expected data center emissions increase in 2030 vs. 2022 would suggest a present value range (7%-10% discount rate) of about $125-$140 bn for the social cost of the incremental emissions from data centers.**

[1] In its report, the EPA characterizes the social cost of carbon as "the value of all future climate change impacts (both negative and positive), including changes in net agricultural productivity, human health effects, property damage from increased flood risk, changes in the frequency and severity of natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services."

[2] Rennert, K., Errickson, F., Prest, B.C. et al. Comprehensive evidence implies a higher social cost of CO2.

AI's Sustainability opportunities: Where to watch and how to measure

As Artificial Intelligence touches an expanding scope of business activities, we see interest from Sustainable investors in understanding how AI can accelerate progress across a range of sustainability objectives. Our previous report, ***AI's Sustainable Solutions***, frames AI-related opportunities across key sectors, including Human Capital, Healthcare, Education, Agriculture, and Climate (Exhibit 19). We identify SDGs in which we see the greatest potential for AI-impact and propose metrics that may help investors assess the value of AI-benefits relative to the negative value caused by higher emissions and social risks.

Exhibit 19: We see AI accelerating progress across a range of Sustainable Development Goals (SDGs)

Source: Goldman Sachs Global Investment Research

- **Healthcare: Accelerating discovery and care (SDG 3).** Massive amounts of healthcare data are produced every day from a range of diverse sources, providing a rich opportunity for the application of AI-based technologies to drive innovation across drug discovery & design, clinical trials, healthcare analytics, tools & diagnostics, and personalized care.
  - Metrics: Value for new drug/vaccine/therapeutic products linked to AI acceleration, value for efficiency gains for swifter drug development timeline to market, value for efficiency
- **Agriculture: Improving yields and reducing waste (SDG 2).** AI-enabled applications stand to improve agricultural outcomes all the way from enhanced

insights into what to plant and when to improve logistics that reduce time-to-market for perishable goods. Precision agriculture — data driven approaches to farming (crops & livestock), is the broadest category where leveraging AI can help to improve yields and reduce waste. However, beyond the myriad of AI applications that fall under the precision ag umbrella, AI also stands to help improve agricultural supply chain safety, speed and transparency.

  - Metrics: Value of improved crop yield, value of reduced resource usage (water, fertilizer)

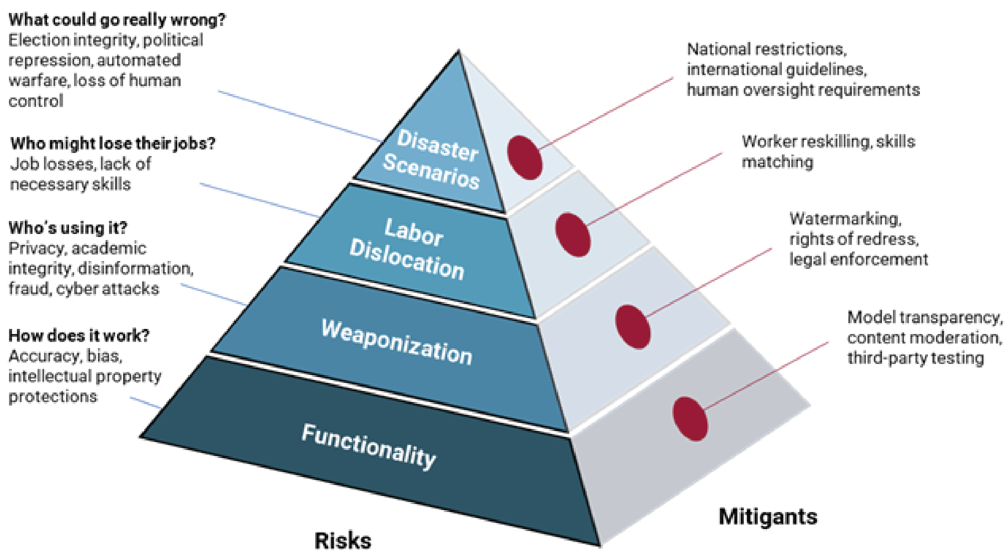
- **Climate Solutions: Optimization and efficiency in power generation and physical assets (SDG 7, 9).** AI holds promise for being a contributor in mitigating the impact of climate change in a wide range of applications, including renewable energy optimization (e.g., weather forecasting, operational scheduling, battery storage optimization); physical asset and power use optimization (e.g., dynamic heating/cooling, data center efficiency, manufacturing efficiencies); and climate modeling.
  - Metrics: Value of linked power generation/utilization efficiency , value/level of reduction in emissions and emissions intensity
- **Human Capital: The opportunity and need for reskilling and upskilling (SDG 8).** Increasing adoption of advanced technologies such as AI create a growing need for educational platforms that enable 'reskilling' and 'upskilling.' We also anticipate greater demand for human capital management tools that can help identify and match rapidly shifting worker competencies with organizational needs ('skills matching').
  - Metrics: Economic productivity, value of employees re-skilled/re-purposed for different roles, value of certifications earned
- **Education: A step change in interactivity and personalization (SDG 4).** AI is complementing e-learning effectiveness through leaps forward in personalization and interactivity. Software-based e-learning platforms can leverage AI to create cost-effective custom study sequences to fit an individual's needs, track progress, and enable self-directed learning, while AI-powered chatbots are making the future of interactivity a reality. Education is especially relevant in periods of technological acceleration in which workers must upskill, and job seekers must gain new skills.
  - Metrics: Value of linked improvement to student test scores, value of linked enablement of certifications / degrees earned

Key risks include both how AI models work and how they're likely to be used. The first order of concerns related to AI center on how the models work, including informational accuracy, transparency, potential algorithmic bias, and intellectual property protections. A next order of risk encompasses the 'weaponization' of AI models, and includes privacy, academic integrity, disinformation, fraud and cyber attacks. In each of these cases, AI enables potential threats to be propagated at new levels of speed, scale and customization. Potential impact on jobs is perhaps a less immediate, but overarching concern. Our economists estimate that roughly two-thirds of current jobs are exposed to some degree of AI automation, and that generative AI could substitute up to one-fourth of current work. The highest order of potential impacts includes more extreme tail risks of societal destabilization and disaster scenarios, such as the manipulation of elections, political repression, or automated warfare (Exhibit 20).

What can be done to mitigate key risks? Creators of AI models will be pressed for transparency and accountability. This would include mechanisms to alert users to AI-generated content and authorship ('watermarking'), warning labels, and disclosures of how the systems are trained and how they work. Voluntary commitments from creators are already being made including the enablement of independent audits and third-party testing, while corporate users are putting into place frameworks for ethical use of AI. Regulations will also play a central role in mitigating AI risks. With the EU AI Act, Europe was the first to pass a comprehensive AI-related legal framework. The AI Act proposes a risk-based framework that classifies AI systems in four tiers of risk and lists prohibited technologies, disclosures and obligations of AI systems operators, and penalties for non-compliance. The US, UK, and China are among other nations that have proposed their own AI-focused rules and regulations.

Exhibit 20: We frame four principal tiers of risks, ordered by time horizon and potential impact, and mitigants for each

AI-related risks and mitigants

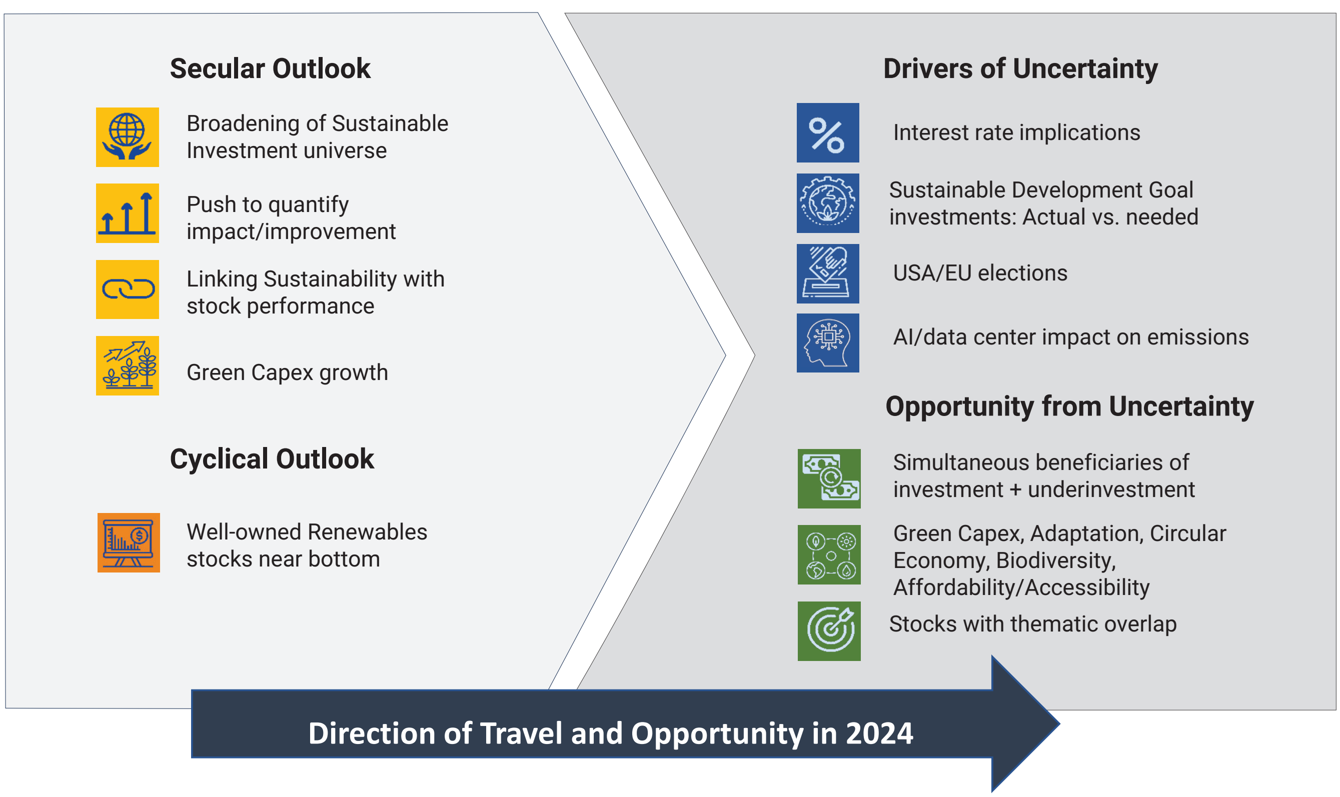


Source: Goldman Sachs Global Investment Research

AI/data center power surge supportive of owning stocks exposed to overlapping sustainable themes

Emissions growth from AI/data centers risks adding to near- to medium-term uncertainty regarding investment needed towards sustainable goals, which we believe supports owning stocks levered to overlapping Sustainable themes among Decarbonization and Adaptation. We believe the secular theme of an expanding investable universe and an Aspiration-to-Action shift towards what's needed to accomplish Sustainable Development Goals will complement cyclical bottoming of sentiment towards quality renewables laggards. AI and data center emissions growth may contribute to uncertainties while at the same time provide near/medium/long-term boosts to renewables generation supply chain via increasing PPAs. We remain secularly bullish on themes like Green Capex, and, in a capital constrained world, efficiency and risk management-driven investment themes — like Circular Economy, Adaptation, Biodiversity and Affordability — are likely to increasingly resonate with investors. Furthermore, a shift in investor focus from investment needs to investments that will actually be made is likely to: (a) further focus on return on capital, not just capital employed; and (b) bring the Dawn of Thematic Convergence, with greater recognition of overlap and interplay among Green Capex sub-themes. This Dawn of Thematic Convergence suggests a focus on stocks levered to multiple Sustainability themes.

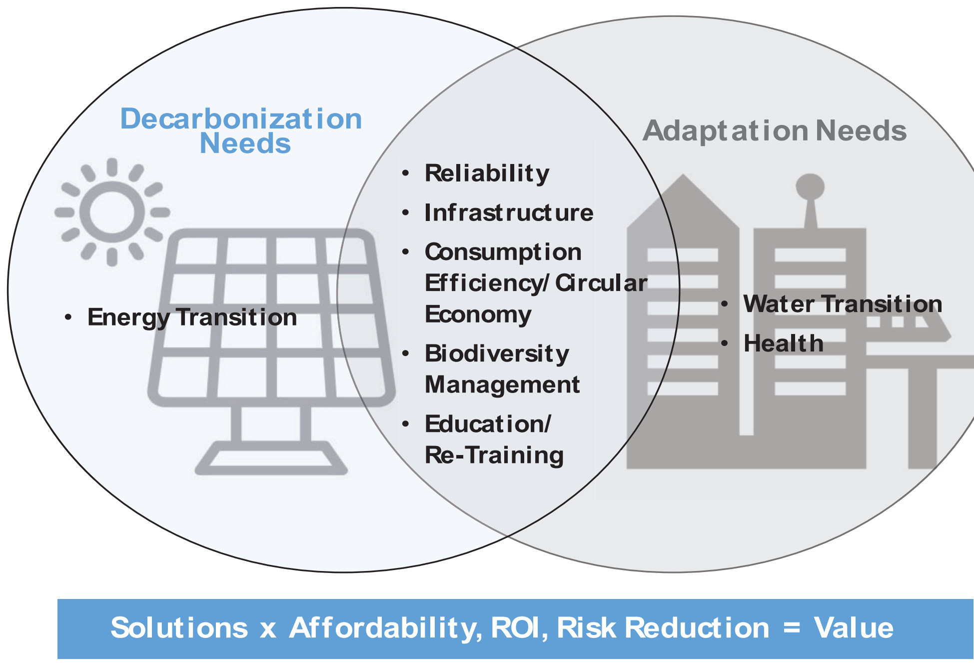
Exhibit 21: We recommend owning companies that are micro beneficiaries of investment across multiple Sustainability themes to mitigate 2024 uncertaitny



Source: Goldman Sachs Global Investment Research

What are implications if actual investment falls short of what's needed? Higher interest rates among other factors are driving greater investor concern over both ability and willingness to fully satisfy needed investments in Green Capex among other Sustainable themes. We believe this will lead to valuation disparities based on which products have cost competitiveness and ability to scale vs. those more challenged/longer term. We also believe the risk of underinvestment will lead to greater focus on driving consumption efficiency and on preparation/reaction to temperature rise. We believe this will support four themes in particular — Circular Economy, Adaptation (reactive and potentially proactive), Affordability and Biodiversity. This Dawn of Thematic Convergence will likely push investors towards looking for companies/products levered to multiple themes that could benefit from both investment or consequences of underinvestment.

Exhibit 22: We see increasing thematic overlap among Infrastructure, Circular Economy, Biodiversity and social themes in part driven by investments (and/or underinvestment) towards Decarbonization and Adaptation



Source: Goldman Sachs Global Investment Research

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Reg AC

We, Brian Singer, CFA, Derek R. Bingham, Brendan Corbett, Carly Davenport, Alberto Gandolfi, Toshiya Hari, Allen Chang, Timothy Zhao, Varsha Venugopal, Evan Tylenda, CFA, Emma Jones, Madeline Meyer, Neil Mehta, Brian Lee, CFA, Daniela Costa, Joe Ritchie, Apoorva Bahadur, Mark Delaney, CFA, Jerry Revich, CFA, Ryo Harada, Christian Hinderaker, CFA, Jacqueline Du, Grace Chen, Xavier Zhang, John Miller and Ati Modak, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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