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Data Centre Energy Use: Critical Review of Models and Results

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Data Centre Energy Use: Critical Review of Models and Results

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George Kamiya [*1]

Vlad C. Coroamă [*2]

[1] Independent Expert, United Kingdom. gkamiya@gmail.com

[2] Roegen Centre for Sustainability, Switzerland. vlad@roegen.ch

** Both authors contributed equally to this research.*

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Executive Summary

There are wide-ranging estimates of data centre energy use in the literature, causing confusion for policymakers and decision-makers. Estimates and projections for 2020 range from less than 200 TWh to 1 200 TWh, while projections for 2030 range from just over 200 TWh to nearly 8 000 TWh – a factor of almost 40.

The objective of this study is to conduct a comprehensive and critical review of existing models and assessments of the energy use of data centres. Based on this analysis, it aims to answer the following research questions:

- How have previous studies estimated data centre energy use, and what factors have contributed to wide-ranging estimates?
- What is the most plausible range for data centre energy use today?
- What best practices should be followed when conducting assessments, and which pitfalls should be avoided?

This study identified and reviewed over 100 articles, reports, and statistics published since 2014, covering thousands of energy estimates and projections from 2010 to 2040 across over 200 scenarios and cases. Nearly half of these publications had been published since January 2024, indicating the recent and rapid growth in interest. The studies cover global, regional, and country-level estimates from academia, industry, governments, and intergovernmental agencies. We also collated published energy data from 60 of the largest data centre operators since 2018. Finally, we reviewed emerging literature on AI energy use in data centres. This is the most comprehensive published review of data centre energy estimates to date.

The publications were reviewed and catalogued on several key attributes, including affiliation, publication type, geographic scope, time horizon, and methodological and modelling approach.

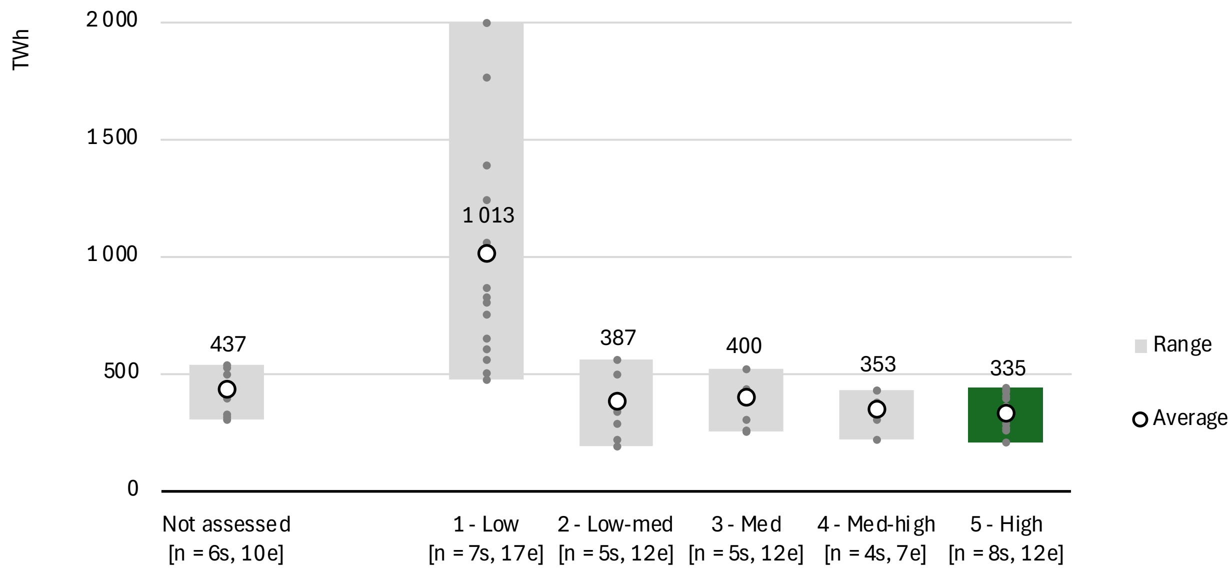
We propose a classification of five different modelling approaches: bottom-up, aggregated totals, temporal proxy extrapolation, hybrid, and other. Aggregated totals are often referred to as “top-down” in the literature and rely on aggregated national or organisational energy consumption data. To distinguish them from true top-down methods such as quantitative systems dynamics or input-output analysis, we prefer “aggregated totals”. Temporal proxy extrapolation uses proxies such as IP traffic and efficiency improvement scenarios to extrapolate projections. Usually referred to simply as “extrapolation”, we suggest the new name to distinguish it from scope or geographic extrapolation.

Each publication’s methods and data sources were evaluated and assessed on a six-point scale of quality: low, low-medium, medium, medium-high, high, and very high. Publications that did not provide sufficient detail regarding their methodologies were categorised as ‘not assessed’.

Studies assessed as ‘low’ – all using temporal extrapolation approaches – had the widest range of estimates and projections for the year 2023, ranging from 480 TWh to 2 000 TWh across 17 scenarios and cases. Studies of higher assessed quality (low-medium and higher, 22 publications) had a much lower and narrower range of estimates (190–560 TWh) across 42 scenarios and cases. The modelling approach is a good predictor for assessment quality, while main author affiliation – perhaps surprisingly – is not.

Global studies assessed as 'high' quality had a range of 210–440 TWh in 2023, with an average base case estimate of 335 TWh. Two further assessment methods helped to corroborate the global review: the review and aggregation of over 80 regional and country-level studies and the aggregation of company-level data from 60 of the largest data centre operators globally.

Figure ES.1 **Estimates of global data centre energy use in 2023, by assessed quality**



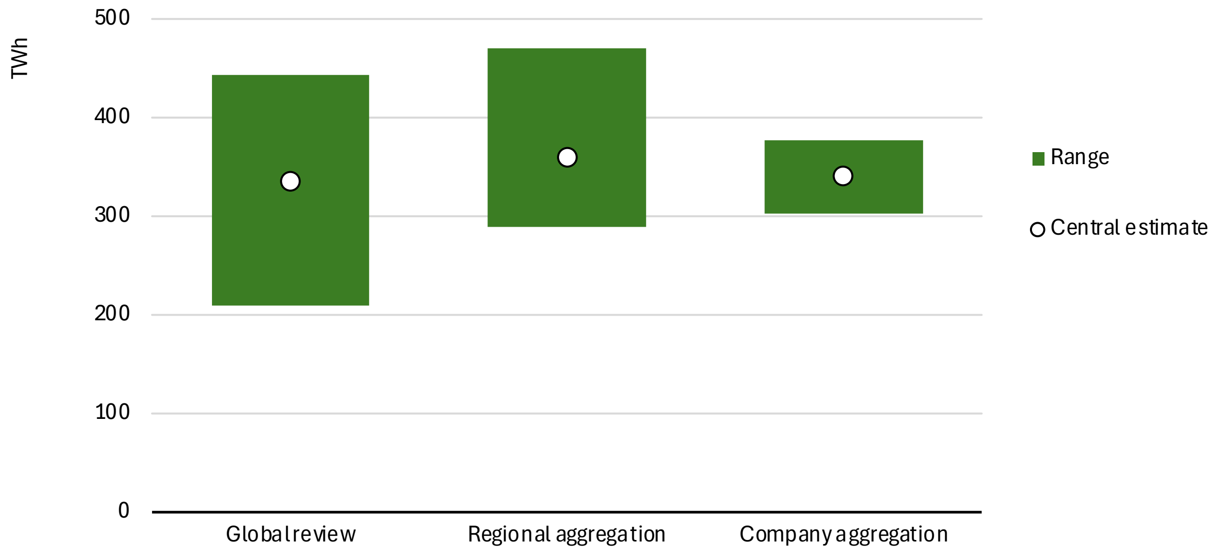
Notes: Range of estimates include all scenarios, while average values are for base cases only. Numbers in parentheses indicate the number of studies (s) and estimates (e). "Not assessed" are studies that did not share sufficient methodological detail to assess their quality.

The regional aggregation approach yielded a global estimate of 290–470 TWh in 2023, with a central (best guess) estimate of 360 TWh. At the regional level, we estimate data centres consumed 125–200 TWh in North America (including 120–195 TWh in US), 105–180 TWh in Asia Pacific (including 70–130 TWh in China), 55–80 TWh in Europe, and 5–10 TWh in other regions.

Based on in-depth analysis of company-level data, we estimate data centres used 300–380 TWh in 2023. This is based on analysis of 60 of the largest data centre operators globally, which we estimate to account for at least three-quarters of the global cloud, colocation, and hyperscale market. We estimate that company-wide electricity use of the four largest data centre operators more than tripled between 2018 and 2023 from around 35 TWh to over 110 TWh, with data centres likely accounting for around 80% of it, or around 90 TWh.

We therefore estimate that data centres globally consumed 300–380 TWh in 2023 (excluding crypto) based on analysis of over 100 studies published since 2014 and data from over 60 of the largest data centre operators.

Figure ES.2 **Results of three complementary approaches to estimate global data centre energy use, 2023**



Notes: Global review includes studies that were assessed to be '6 - High'. Central estimate indicates authors' best estimate.

Artificial intelligence – particularly generative AI – is widely expected to be a key driver of near-term growth in data centre energy use. Several studies have estimated the current and future energy use of AI in data centres, focusing on the energy use of AI accelerators such as GPU. These studies estimate current AI-related energy use to be relatively low at 10–50 TWh (5–15% of global data centre energy use in 2023), but project this to increase rapidly to 200–900 TWh by 2030. We estimate a plausible range of AI data centre consumption of 200-400 TWh in 2030 (35-50% of overall data centre energy use projected in 2030).

Journalists, policymakers, and other non-experts are encouraged to critically assess the quality of data centre energy estimates. They can ask questions related to data quality and methodologies, analytical scope, and the domain expertise of the authors to assess the quality of publications to avoid amplifying poor quality analysis. Journalists in particular are advised to avoid cherry-picking the most extreme scenario results that exaggerate or downplay the energy and environmental impact of data centres.

In this complex and dynamic field, companies, governments, researchers, and other stakeholders are called upon to contribute to more rigorous estimates. Companies and governments should improve data accessibility and transparency through systematically collecting and publicly reporting timely, high-quality data. Energy modellers should clearly define system boundaries and collect data instead of making assumptions whenever possible. They should also avoid projections reaching more than five years into the future.

1. Introduction

The digital infrastructure, devices, and technologies that underpin the digital transformation have a range of energy, climate, and other environmental impacts.

Given the urgency of the climate crisis, rapid developments in technology and behaviour, and important but uncertain impacts of digitalisation, there is a critical need to better understand the current and near-term energy and climate impacts of digitalisation to inform sound policymaking.

1.1 Background

Published estimates of the energy use of the global information and communication technology (ICT) sector, including data centres, differ substantially. For example, data centre energy use estimates and projections for 2020 diverge by a factor of six from around 200 TWh (Malmodin et al., 2024; Masanet et al., 2020) to 1 200 TWh (Andrae & Edler, 2015). Projections and scenarios for 2030 diverge by nearly 40-times.

These wide-ranging and inconsistent estimates frustrate public understanding and pose challenges for thoughtful policymaking. The lack of statistical data from governments as well as standardised methodologies and assumptions in the field contribute to perpetuating these challenges (Bremer et al., 2023). At the same time, the topic is gaining greater importance and attention due to the rise of artificial intelligence (AI) and the associated concerns about its rapid growth in energy consumption (de Vries, 2023; IEA, 2024a).

1.2 Scope of the study

This study sets out to critically review existing models and assessments of the energy use of data centres (DCs), together with their deployed assessment methods. It provides a critical and objective analysis of the existing literature to provide clear and actionable insights to conduct robust assessments on the energy use of DCs to inform policy and technology choices to mitigate their impacts.

The scope of the study includes:

- **Metric and functional unit:** the annual energy consumption (expressed in terawatt-hours per year [TWh/year]) of data centres. Where possible, we extract energy data from studies using other metrics (e.g., greenhouse gas (GHG) emissions that we back-calculate to electricity use).
- **Types of data centres:** all categories of data centres are covered, notably the three categories often distinguished in the literature: hyperscale, colocation, and enterprise DCs. Due to its growing importance, the artificial intelligence (AI) server capacity is – to the extent possible – singled out within the sum of all DCs. Cryptocurrency mining is excluded from the analysis.
- **Lifecycle phases**: as the operational (use phase) energy dominates the lifecycle of data centres (Masanet et al., 2013) and most of the available

literature focuses on this phase, we focus on operational energy and exclude production and end-of-life energy from the scope of analysis.

- **Devices and equipment within data centres:** complete scope of DCs, comprising servers, storage, networking, and infrastructure (e.g. cooling, lighting).
- **Geography**: worldwide, as well as country, regional, and company-level data to devise their share towards the total.
- **Time horizon**: both historical analyses (2010 onwards) and projections (up to 2030).
- **Publication date**: since 2014.

Hence, the analysis does not include other types of environmental impacts (e.g., GHGs, water or resource consumption), further ICT subsectors beyond DCs (such as telecommunication networks or end-user devices), hardware dedicated to crypto mining, other life cycle phases (i.e., production or end-of-life), and older studies (i.e., publications prior to 2014 or values older than 2010).

1.3 Objectives and approach

The main objective of this study is to conduct a comprehensive and critical review of published assessments of the energy use of data centres, including their deployed models and methods.

Our approach aims to both cover more studies and provide critical assessments which are lacking in some previous reviews such as Freitag et al. (2020, 2021). Reviews that are not comprehensive (i.e., only covering a select few studies) or uncritical (i.e., showing results from studies as equally valid) risk being misinterpreted by readers.

The study aims to answer the following research questions:

1. How have previous studies estimated data centre energy use, and what factors have contributed to wide-ranging estimates?
2. What is the most plausible range for data centre energy use today?
3. What best practices should be followed when conducting assessments, and which pitfalls should be avoided?

To address these questions, the remainder of the report is organised as follows.

Chapter 2 provides an overview of the methodology employed by this study for all the three research questions above.

Chapter 3 summarises the critical review of data centre energy estimates from a range of available sources, including government data and reports, peer-reviewed journal articles, industry data and reports, and other grey literature. It shows the range of estimates for DCs globally and for key countries and regions as well as the estimates for AI energy consumption in DCs. It also presents a short summary for each of the approaches, which determines the individual quality assessments. It also presents an own 2023 assessment based on aggregating company-level energy data from large data centre operators.

Building on these results, **Chapter 4** summarises the approach used to estimate global data centre energy consumption in 2023. **Chapter 5** summarises the results of the study and discusses key strengths and limitations of the analysis.

Chapter 6 concludes the report with key recommendations for analysts conducting assessments of data centre energy use and guidelines for those interpreting these assessments.

2. Methodology

As discussed in Section 3.2 and shown in Figure 3.1, there are wide-ranging estimates of data centre (DC) energy consumption, with some near-term projections diverging by more than an order of magnitude.

These differences and inconsistencies stem from several key causes, including a lack of reliable data combined with differences in underlying assumptions, modelling approaches, and system boundaries.

2.1 Summary of overall approach

To address these inconsistencies and answer the three related research questions introduced in Section 1.3, we proceeded as follows:

- Gathered relevant data centre energy estimates published since 2014, including academic publications, reports and statistics from governments and intergovernmental agencies, and industry reports.
- Catalogued the publications and estimates according by key parameters such as modelling approach, system and geographic boundaries, time horizon, and publication type.
- Extracted numerical values from the studies to compare estimates at different geographic and technological scopes (e.g. global, US, Europe, AI).
- Conducted a critical assessment of the quality of each publication based on several criteria such as modelling approach or the robustness of underlying data and assumptions.
- Presented a new, narrower range of data centre energy estimates based on the high-quality studies at the global, regional, and country levels and analysis of company-level data.
- We conclude the study with a list of recommended best practices that should be followed when conducting such assessments.

2.2 Choice of literature

The study reviews recent literature on data centre (DC) energy demand at the global, regional, and national levels. Given the heterogeneity of publications, this work could not be performed merely as a traditional academic literature review. While some of the studies reviewed are indeed peer-reviewed journal papers, a number of other pivotal studies have been published at non-indexed venues and would not appear in a systematic database search of the scientific literature.

These include contributions in conferences, such as the ICT4S (ICT for Sustainability) conference proceedings, as well as key studies published by reputable organisations such as the International Energy Agency (IEA, 2023b, 2024a), Efficient, Demand Flexible Networked Appliances (EDNA, 2019a, 2019b, 2021), and the European Commission (Kamiya & Bertoldi, 2024), which would also not show up in academic database searches. Most of the existing assessments of AI energy consumption also come from the industry (EPRI, 2024; Schneider Electric, 2023) or consultancy companies, e.g. (Lee, 2023; Semianalysis, 2024). Finally, several of the most valuable primary data sources are studies stemming in the ICT industry itself, which is typically scattered across company sustainability reports, white papers, press releases, and websites.

Overall, we identified and reviewed over 100 publications (excluding the duplicates which appear in several categories) as presented in Table 2.1. These publications include thousands of energy estimates and projections from 2010 to 2040 across over 200 scenarios and cases. Nearly half of all studies reviewed had been published since January 2024, indicating the recent surge in interest in the topic. Almost all studies focused on the US have been published since 2024.

Table 2.1 Overview of reviewed literature

Scope	Number of studies (scenarios / estimates)	Studies
Global	51 (75)	Andrae, 2017, 2019a, 2019b, 2020; Andrae & Edler, 2015; BCG, 2025; Belkhir & Elmeligi, 2018; Bordage, 2019; Crenes & Criqui, 2018; Deloitte Global, 2024; EDNA, 2019b, 2021; Gas Exporting Countries Forum, 2024; GeSI, 2015; Goldman Sachs, 2024; Graham, 2024; Greenpeace, 2017; GSMA Intelligence, 2024; Hintemann & Hinterholzer, 2019a, 2020, 2022; IDC, 2024a, 2024c; IDTechEx, 2025; IEA, 2014, 2017, 2019, 2020, 2021, 2022b, 2023b, 2024a, 2024b; ITU, 2020; Jeffries, 2024; Koot & Wijnhoven, 2021; Liebreich, 2025; Liu et al., 2020; Malmodin et al., 2024; Malmodin & Lundén, 2018; Masanet et al., 2020; Schneider Electric, 2021, 2023; TD Securities, 2024; The Shift Project, 2019, 2021b, 2021a, 2024; Thunder Said Energy, 2025; Van Heddeghem et al., 2014; World Bank & ITU, 2024
United States	23 (35)	BCG, 2023, 2024; EPRI, 2024; Goldman Sachs, 2024; Guidi et al., 2024; IDC, 2024a; IEA, 2024a; Jeffries, 2024; Lee, 2023, 2024; Liebreich, 2025; Masanet et al., 2020; McKinsey, 2023, 2024a; Rhodium Group, 2024; Rystad Energy, 2024; Semianalysis, 2024; Shehabi et al., 2016, 2018, 2024; S&P Global, 2024; S&P Global Commodity Insights, 2024; S&P Global Market Intelligence, 2024a, 2024b; TD Securities, 2024; The Economist, 2024
Europe	44 (60)	Ademe & Arcep, 2022; Arcep, 2024; Avgerinou et al., 2017; Bashroush, 2018; Bertoldi et al., 2017; Beyond Fossil Fuels, 2025; Bio by Deloitte & Fraunhofer IZM, 2014; Bitkom & Hintemann, 2021; BloombergNEF et al., 2021; Bordage et al., 2021; Central Statistics Office, Ireland, 2021, 2022, 2023; CITIZING, 2020; COWI, 2018, 2021; Danish Energy Agency, 2021, 2022, 2023; Dodd et al., 2020; Hintemann et al., 2023; Hintemann & Hinterholzer, 2020, 2022; ICIS, 2024; Kamiya & Bertoldi, 2024; Lannelongue et al., 2024; McKinsey, 2024b; Montevecchi et al., 2020; National Grid ESO, 2022, 2024; Node Pole & CBRE, 2022; NVE, 2024; NVE (Norwegian Water Resources and Energy Directorate), 2023; Orkustofnun, 2024; Prakash et al., 2014; Radar, 2020; Statistics Finland, 2022; Statistics Netherlands, 2021a, 2021b, 2022; Swedish Energy Agency, 2023; Traficom, 2023; VHK & Viegand Maagøe, 2020
China	11 (11)	China Academy of Information and Communications Technology, 2023; Chinese Electronics Standardization Institute, 2022; Development Research Center of the State Council, 2024; Fan, 2021; Greenpeace East Asia, 2021; Greenpeace East Asia and North China Electric Power University, 2019; IEA, 2025; Jeffries, 2024; Li et al., 2024; Open Data Center Committee, 2022; Xie, Han and Tan, 2024
Other countries	12 (12)	Bain et al., 2021; CRIEPI, 2024; Deloitte Tohmatsu MIC Research Institute, 2022; Hannam, 2024; IEA, 2022a; Japan Atomic Industrial Forum, 2024; Kitchen, 2024; Singapore Energy Markets Authority, 2022, 2023, 2024; Singapore Ministry of Communications and Information, 2021; Vij, 2024
AI (global)	11 (20)	de Vries, 2023; Deloitte Global, 2024; Gartner, 2024a, 2024b; Goldman Sachs, 2024; IDC, 2024c; IEA, 2024a; Morgan Stanley, 2024; RAND, 2025; Schneider Electric, 2023, 2024; Semianalysis, 2024

2.3 Literature classification criteria

Each of the publications and estimates were catalogued each of the publications on the following parameters:

- **Affiliation:** academia, government, industry, non-governmental organisation, mixed
- **Publication type:** peer-reviewed, preprint, report
- **Geographic scope:** global, multi-country, country
- **Time horizon:** historical, projection
- **Methodological and modelling approach:** bottom-up, aggregated totals, temporal proxy extrapolation, hybrid, other (addressed in Section 2.3.1 below).
- **Analytical scope:** data centre types (e.g. enterprise, cloud, hyperscale), specific technologies or topics (AI).

Table 2.2 describes the significance of each of these parameters and lists and briefly describes their possible values.

2.3.1 Modelling approaches – state-of-the-art and own taxonomy

The literature identifies three main approaches for the assessment of data centre energy consumption: "bottom-up", "top-down", and "extrapolation" (Kamiya & Bertoldi, 2024; Mytton & Ashtine, 2022; UNCTAD, 2024). They can be shortly described as follows:

- **Bottom-up** studies combine detailed technology data such as equipment specifications (e.g. server power draw) with estimates of the installed equipment base, to arrive at estimates of overall DC energy consumption.
- **Top-down** studies rely on energy consumption data from governments and companies, making them accurate and easy to update. However, due to limited data availability, they often require complementary methods (such as geographic extrapolation) for full coverage.
- **Extrapolation** approaches project energy consumption into the future based on high-level indicators and proxies such as Internet traffic. They are transparent and easy to update but lack explanatory depth and carry the risk of overestimation in long-term projections.

We largely agree with this taxonomy, but consider two of these three terms imprecise and potentially misinterpreted, and thus propose a new terminology. "Extrapolation" is generally used for temporal extrapolation based on compound annual growth rates or other proxy indicators. Scope extrapolation, however, is also often deployed to widen the scope of the analysis, such as from a few companies to the entire market or from one country to a continent or the world. We thus suggest a more explicit term "temporal proxy extrapolation" for what is often described in the literature as "extrapolation".

Table 2.2 Literature review parameters

Parameter	Description and significance	Types and examples
Affiliation	Organisation(s) that employ the authors of the published analysis or otherwise affiliated or associated with the researcher. Affiliation can provide useful context about the researcher's background, resources, and potential biases.	• Academia: universities and research institutions. • Government: government agencies, government-affiliated laboratories or research institutions, intergovernmental organisations. • Industry: companies, including consultancies and investment banks. • Non-governmental organisation: advocacy, think tanks. • Mixed: more than one of the above types.
Publication type	The type of publication format. Publication type provides an indication of the level of scrutiny and validation the analysis has undergone.	• Peer-reviewed: articles that have been reviewed by relevant experts who assess the research's methodology, results, and conclusions. The peer-review process can – but not always – increase the quality, accuracy, and validity of the research. • Preprint: research papers that have not yet undergone peer review that published publicly available before being submitted to a journal. • Report: other publications with wide-ranging quality and credibility. Some reports such as from intergovernmental organisations undergo extensive external review and can achieve levels of analytical quality equivalent to the highest quality peer-review publications.
Geographic scope	The geographic scope of analysis, e.g. global or country-level. Geographic scope is important to consider the relevance and generalisability of findings.	• Global: studies with global estimates. Some studies may further provide regional or country-level breakdowns. • Multi-country: studies covering multiple countries, typically a region (e.g. European Union). • Country: studies covering a single country.
Time horizon	Indicates whether the study includes retrospective and/or prospective estimates. Time horizon provides important context of the analysis. For example, a projection for 2020 published in 2015 should be interpreted differently than an estimate for 2020 published in 2022.	• Historical: putting forward historic or current values. • Projection: presenting future estimates. • Both: both historical and projections.
Methodological and modelling approach	The primary modelling approach employed by the analysis. Modelling approach provides an important indication of the overall analytical quality and how the results may be interpreted. For example, a global estimate extrapolated from assumptions from a single country may not necessarily be representative, as would a temporal extrapolation 20 years into the future.	• Bottom-up: combining bottom-up data such as installed server base with per-server consumption. • Aggregated totals: aggregation of company or national measurements of DC energy consumption. • Temporal proxy extrapolation: extrapolation of proxy indicators to project future DC consumption. • Other: other approaches such as quantitative system dynamics. • Hybrid: combines multiple approaches.
Analytical scope	The inclusion (or exclusion) of specific data centre types and/or specific digital technologies. Analytical scope is important to consider completeness of the analysis and to ensure comparability between studies.	• Data centre types (e.g. enterprise, cloud, hyperscale) • Coverage of emerging technologies (AI)

Additionally, we propose the term "aggregated totals" instead of "top-down" for three reasons. First, because "top-down" can be interpreted in different ways. Bottom-up assessments also deploy large statistics of national or global server sales, which might justify the term "top-down" as well. Explicitly showing that this method of aggregated totals, as opposed to aggregating equipment-level data in bottom-up assessments, eliminates this potential confusion.

Additionally, what is typically described as "top-down" often implies several layers of aggregation: individual server rooms or buildings are aggregated into a total DC site consumption, all sites of an organisation or a country are aggregated to a company- or country-level number, and several companies (e.g., the "big five", Amazon, Apple, Google, Meta, and Microsoft) or several countries can also be aggregated to larger entities – the name "aggregated totals" naturally reflects the possibility of several such layers of aggregation.

Finally, what the ICT energy consumption literature refers to as "bottom-up", largely coincides with what the energy systems modelling literature describes as "bottom-up" as well. In energy system modelling, however, "top-down" models often deploy macroeconomic proxies such as economic growth, employment levels, or competitiveness, from which projected energy consumption is then derived (Herbst et al., 2012). They are thus rather like the [temporal proxy] "extrapolation" models of the DC energy literature. Using the term "top-down" to describe something quite different might confuse the energy modelling community which is increasingly taking an interest in DC energy modelling.

We classify studies into one of five approaches defined and explained below. As most studies rely on a combination of approaches, we classify them in the most appropriate category based on the predominant approach employed.

1. **Bottom-up**: Based on estimates of the installed server and IT equipment base combined with equipment specifications (such as the average server power consumption), equipment lifespans, and other energy-influencing attributes (such as power-usage effectiveness [PUE])[1].

2. **Aggregated totals**: Often described in the literature as "top-down" (Kamiya & Bertoldi, 2024; Masanet et al., 2024; Mytton & Ashtine, 2022; UNCTAD, 2024), this approach relies on national, regional, or organisational energy consumption data, which have been directly measured or estimated at an aggregate level.

3. **Temporal proxy extrapolation**: Starting from an initial base estimate obtained from either of the methods above, high-level proxies and indicators such as data traffic and energy intensity assumptions are combined to extrapolate projections of DC energy use under varying activity and efficiency improvement scenarios. Mytton and Ashtine (2022) refer to this method simply "extrapolation"; to distinguish it from scope and geographic extrapolation (discussed below), we refer to this as "temporal proxy extrapolation".

[1] Although some bottom-up studies may include temporal extrapolations of demand drivers such as hardware shipments or projected service demand, where extrapolations are on bottom-up data (rather than proxies such as data traffic), we classify these as primarily 'bottom-up' approaches.

4. **Other**: Other methods have occasionally also been deployed. They include actual top-down modelling methods (and not the aggregated totals often misnamed as such) such as quantitative system dynamics modelling (Schneider Electric, 2024) or economic input-output analyses.

5. **Hybrid** approaches are where more than one of the above approaches is used and there is no clear predominant approach. For example, a hybrid estimate might combine aggregated country-level totals, combined with bottom-up data or extrapolation approaches.

2.3.2 Modelling approaches – advantages and drawbacks

Each of these methods has its advantages and drawbacks. Bottom-up models based on credible sources are considered to be high quality and offer strong explanatory power for assessing policy and technological effects. However, they are resource-intensive due to significant data requirements. Additionally, their transparency is limited, as some data sources are often expensive or proprietary. Finally, with the advent of AI and general diversification of server types, scope extrapolations (see below) from some data centres to others become less reliable.

Aggregated totals typically rely on credible sources of measured data or estimates (e.g. company data) and are generally considered to be of high quality. However, due to their limited scope, these studies may require some scope extrapolation (e.g. for full coverage of companies or countries – see below). They also do not typically disaggregate energy consumption sources and drivers within data centres (e.g. servers, infrastructure), limiting their ability to assess underlying drivers of technological developments and developing future projections.

Temporal proxy extrapolation approaches are typically more transparent and relatively easy to generate and update. Their main disadvantages are their low explanatory power and a higher risk of misuse (e.g. developing exaggerated estimates from long-term projections). Studies that rely primarily on temporal proxy extrapolations are generally considered to be of low quality, particularly for projections that extend beyond two or three years.

As a complement to either of the methods above, **scope extrapolation** is often deployed for broader results. It is used to broaden the scope, e.g. by geographically scaling up the results, such as from a country to a continent or the world. It can also be used to broaden the scope from some companies to the entire market, e.g. based on market shares.

Hybrid approaches can be used for corroborating results and to take advantage of the specific strengths of bottom-up and aggregated totals; they are at risk, however, to also combine both their drawbacks and to induce system boundary uncertainties and thus double-counting.

2.4 Extracting numerical results

We extracted the numerical values for the yearly energy consumption from each study. In line with the vast majority of the literature, we only documented the operational energy consumption (i.e., the use phase), not production or end-of-life. We excluded blockchain and cryptocurrencies from the few assessments that did explicitly include it.

In a large spreadsheet, we documented each study with its numerical values in a row, together with the starting and ending year of the assessment, the year used as base for future projections, if applicable. If the study had several scenarios (e.g., “best”, “expected”, “worse”), we documented each such scenario (along with its name) in a dedicated row of the spreadsheet. Likewise, if a source was simultaneously covering different geographies (e.g., Germany and the world) or different analytical scopes (e.g., DCs overall and AI only), each of these scopes was individually recorded.

Each year between 2010 and 2030 was represented by a column, and all values within this range that were explicitly mentioned in the study were correspondingly documented. Years earlier than 2010 were not documented. For the few studies with projections beyond 2030, we documented their values every 5 years until 2050 (i.e., for 2035, 2040, 2045, and 2050), but did not use this information further.

When results were not explicitly numerical, but only implicitly in a graph, we use the WebPlotDigitizer tool (automeris.io, 2024) to approximate numerical values consistently, and as precisely as possible.

If only GHG emissions were published, we converted them to electricity using each publication’s stated carbon intensity of electricity assumptions. For publications that did not include their own carbon intensity of electricity, we used carbon intensity data from the International Energy Agency and Our World in Data (IEA, 2023a; Our World in Data, 2024).

2.5 Quality assessment

To assess the quality of the reviewed studies, we considered several criteria, including:

- The quality of the approach (or combination of approaches) deployed.
- The quality, timeliness, and representativeness of the data sources used.
- The severity of remaining data gaps and the appropriateness of the assumptions used to fill them.

Although initially planned, it has proven challenging to define a rigid scheme for grading each of these criteria and then weighing them together. Along each of the dimensions, reality is complex and full of nuances, and at the same time the methodologies, assumptions and data sources used by the individual studies too diverse to devise objective conditions accounting for all of them.

Moreover, even when studies use similar methods, data sources, and assumptions, it is still challenging to define objective criteria for their assessment. Hintemann and Hinterholzer (2019) and Malmodin et al. (2024), for example, both use the same bottom-up approach (which will be discussed in Chapter 3) based on primary data of the highest-possible quality, but covering different geographies: Hintemann and Hinterholzer (2019) base their analysis on virtually all data centres in Germany, while Malmodin et al. (2024) collected data from major global data centre (DC) operators covering about 50% of all DCs in the world. Both studies then used geographic scope extrapolation to generalise from their sample to the whole world.

When one study covers about 50% of worldwide DCs, while the other only reflects about 5% of them, the geographic extrapolation of the former is probably more reliable. But how much more reliable, how can the difference be quantified (as it is certainly not 10 times better)? And there are further subtleties: The geographically restricted study covers with a high degree of certainty all relevant DCs in Germany. Due to the sheer amount of data and the heterogeneity among companies in their system boundary definitions, data collection, and reporting, the uncertainties for the broader study are naturally higher, including the self-reported estimate of 50% coverage. One study is thus broader but with likely less precision, making an objective comparative quality assessment even more challenging.

In such a complex reality, objective criteria may be insufficient because they attempt to simplify and quantify intricacies that cannot be fully captured by rigid standards. By presenting an illusion of certainty, these criteria can mislead decision-making, overlooking important nuances and unpredictable factors.

Given these challenges in the objectification attempt of study quality, a different approach was ultimately deployed. Based on their extensive experience in the field, both authors independently and subjectively assessed the quality of each of the reviewed studies on a scale from 1 to 6 (‘low’, ‘low-medium’, ‘medium’, ‘medium-high’, ‘high’, ‘very high’). Any differences in the independent assessments were discussed to arrive at a final consensus assessment.

While some company-level and country-level data (such as national statistics) were assessed to be ‘very high’, no global studies were assessed to be ‘very high’ given the lack of comprehensive and official data. Studies without sufficient methodological detail could not be adequately assessed and were thus not ranked on the six-point scale.

2.6 Deriving global estimates

Chapter 4 derives global estimates of DC energy consumption for 2023 based on the literature. To achieve this goal, three different approaches were used.

First, we focused on the higher-quality global estimates from the analysis, i.e. those categorised as ‘high’ in Section 3.1. These results are presented in Section 4.2.

Second, we look at high quality estimates at the country and regional levels in Section 3.2, aggregating them globally in Section 4.3. Finally, we analyse company-level data for 60 of the largest DC operators in the world, aggregating it globally in Section 4.4.

These three complementary approaches of reaching global estimates for DC energy consumption based on different perspectives and data sources help to triangulate our final estimate for global data centre energy use in 2023.

3. Critical review

National and regional governments and intergovernmental organisations such as the International Energy Agency (IEA) collect, validate, and publish official statistics on the energy use of many end-use sectors and services. However, most governments do not yet collect or publish official statistics on energy use by data centres. Instead, data centre energy consumption is typically included within the wider commercial buildings sector.

In the absence of official national and international statistics and data, various organisations and researchers have estimated the energy use of data centres at national, regional, and global levels. These estimates have been derived using a range of modelling approaches, data sources, and assumptions.

This chapter compiles and critically reviews data centre energy estimates published over the past 10 years.

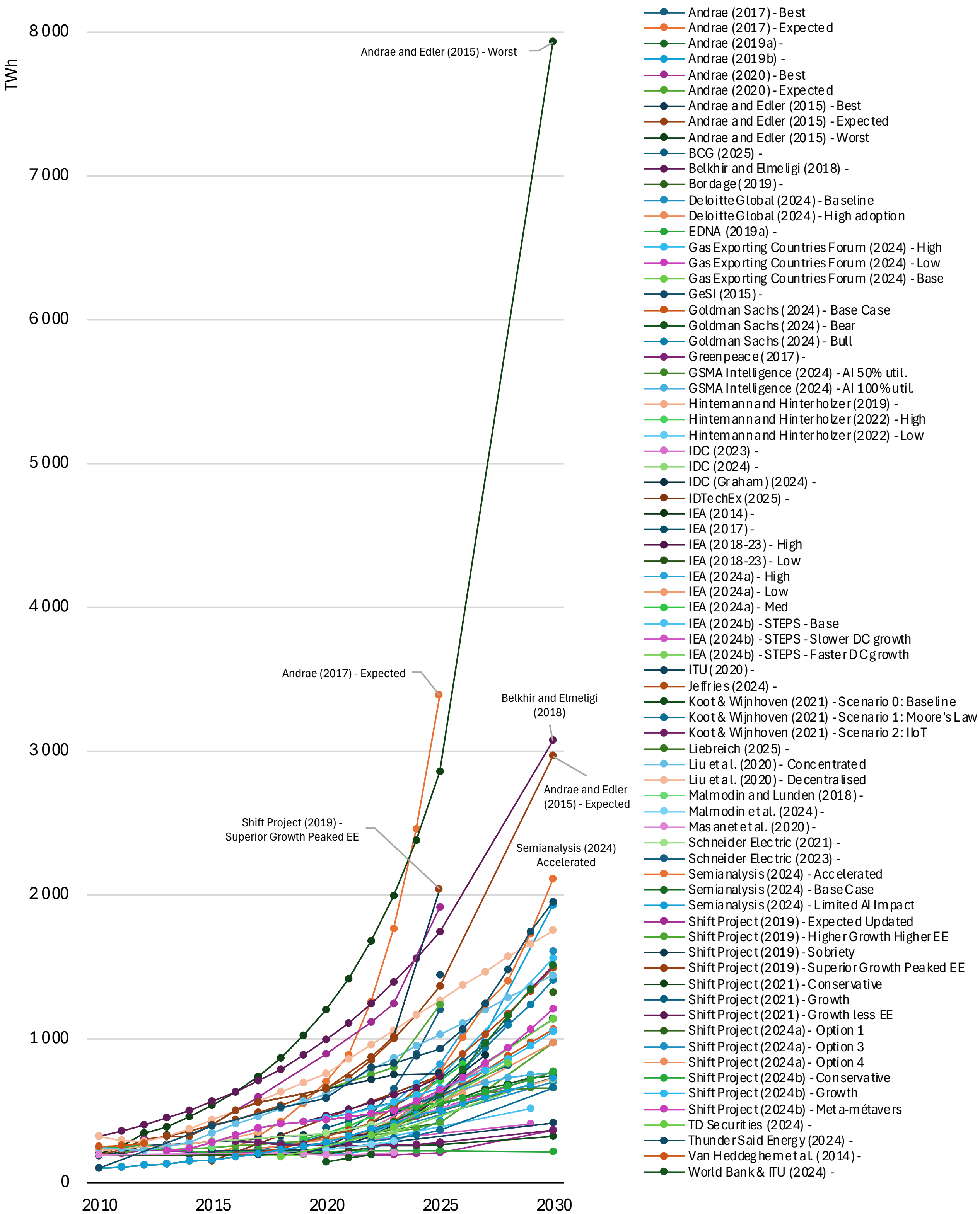
3.1 Global estimates

We identified over 50 publications with global data centre energy estimates published since 2014. The published estimates and projections for global data centre energy use are wide-ranging. For example, estimates and projections for 2020 range by a factor of six (200–1 200 TWh), while projections for 2030 range by almost 40-times (210–7 900 TWh) (Figure 3.1).

These studies employ a wide range of methodologies and assumptions. Mytton & Ashtine (2022) conducted a critical and comprehensive review of these and other studies, covering a total of 46 publications. Their review notes several key flaws with some of the studies and identifies recommendations for future studies.

Table 3.1 summarises key global studies, including a summary of methods and sources, results, and our quality assessment with a brief rationale.

Figure 3.1 Global data centre energy estimates and projections published since 2014



Note: All published estimates are shown to illustrate the full range of estimates and projections.

Table 3.1 Overview of studies estimating global data centre energy use

Institution and publications	Summary	Results	Quality assessment
Beijing Normal University; Global Energy Interconnection Development and Cooperation Organization (GEIDCO)			
Liu et al. (2020)	Temporal proxy approach based primarily on assumptions and approach in Andrae and Edler (2015), with adjusted projections for PUE under different decentralisation scenarios.	450-550 TWh in 2017 Projection: 600-800 TWh in 2020	Low – based primarily on temporal extrapolation approach.
Borderstep Institute			
Hintemann and Hinterholzer (2020)	Based primarily on bottom-up data centre market developments (primarily in Europe), technical characteristics of servers, storage, and networking (energy use, age) and data centre infrastructure (air conditioning, power supply, UPS), extrapolated geographically to the world.	310-330 TWh in 2018 (400 TWh including crypto)	Medium-high – uses bottom-up data and assumptions based on detailed studies for Germany; however, there is limited detail regarding data sources and assumptions at the global level.
Hintemann and Hinterholzer (2022)		270-380 TWh in 2020 (350-500 TWh including crypto)	
Boston Consulting Group (BCG)			
BCG (2025)	Methodology not disclosed; sources are "BCG Global Data Center Model; expert interviews; MLPerf; Nvidia quarterly earnings; press releases; product datasheets".	43 GW in 2020 (377 TWh) 60 GW in 2023 (526 TWh) Projection: 127 GW in 2030 (1 113 TWh)	N/A – cannot be assessed due to lack of methodological details.
Deloitte			
Deloitte Global (2024)	Bottom-up approach considering server types, IT equipment and energy efficiency trends based on IDC assumptions for 2024-2030 and diffusion model (logistic growth assumptions) for 2030 to 2050.	380 TWh in 2023 Projections: 700–970 TWh in 2030 1 140–2 660 TWh in 2040 1 680–3 550 TWh in 2050	Medium-high – near-term assessment to 2030 uses credible market assumptions (IDC); long-term scenarios highly uncertain.
Ericsson; Telia			
Malmodin and Lundén (2018)	Hybrid estimate based on reported company data, benchmarking to other studies, and bottom-up data on hardware shipments.	220 TWh in 2015 (245 TWh including enterprise networks)	High – relies on combination of company-level data covering most of the largest data centre operators in the world.
Malmodin et al. (2024)		223 TWh in 2020	
Gas Exporting Countries Forum (GECF)			
Gas Exporting Countries Forum (2024)	Temporal extrapolation under three efficiency and adoption scenarios (Low, Base, High) with historical numbers based on Goldman Sachs (2024).	240 TWh in 2023 Projections: 510-730 TWh in 2025 770-1570 TWh in 2030	Low-medium – primarily a temporal extrapolation under different efficiency scenarios.
Ghent University			
Van Heddeghem et al. (2014)	Bottom-up methodology similar to Koomey (2008), multiplying the average power per server by the number of servers worldwide for three server classes, and adding electricity used by storage equipment, network equipment and switches, and infrastructure.	270 TWh in 2012	Medium-high – uses bottom-up approach split by server classes.

Institution and publications	Summary	Results	Quality assessment
Goldman Sachs			
Goldman Sachs (2024)	Hybrid approach based on initial high range of IEA estimate for 2022 with temporal extrapolations of Cisco workload projections and efficiency improvement trends of 3% in base case. For AI energy use, combines projected AI server shipments (bottom-up) and power efficiency improvement of 8-15% per year (extrapolation).	240 TWh in 2020 350 TWh in 2022 Projection: 740–1 400 TWh in 2030	Medium – uses some bottom-up drivers but also includes temporal extrapolation of efficiency.
GreenIT.fr			
Bordage (2019)	Based on the number of servers in operation and LCAs of three different data centres.	312 TWh in 2019	Low – based on a small and unrepresentative set of assumptions.
GSMA Intelligence			
GSMA Intelligence (2024)	No methodology disclosed.	338 TWh in 2022 Projections: 1.75-2% of global electricity use in 2030 (~650-750 TWh)	N/A – cannot be assessed due to lack of methodological details.
Huawei			
Andrae & Edler (2015)	Temporal proxy extrapolation with data centre IP traffic extrapolations and energy intensity per unit of IP traffic under three efficiency improvement scenarios (expected, best, worst).	397 TWh in 2015 ("Expected" case) Projections: 345-1200 TWh in 2020 1140-8000 TWh in 2030	Low – uses a poor proxy for energy consumption (data centre IP traffic) and unclear methodological basis for efficiency assumptions.
Andrae (2019a)	Updated IP traffic and energy efficiency assumptions from 2015 study, exploring additional scenarios of varying data traffic growth rates and efficiency improvement rates.	220 TWh in 2015 Base projections: 299 TWh in 2020 412 TWh in 2025 974 TWh in 2030	Low-medium – similar to Andrae & Edler (2015) but includes updated assumptions to reflect recent efficiency and traffic trends.
Andrae (2019b)	Updated IP traffic and energy efficiency assumptions from 2015 study.	211 TWh in 2018 Base projections: 207 TWh in 2020 429 TWh in 2025 1 929 TWh in 2030	Low-medium – similar to Andrae & Edler (2015) but includes updated assumptions to reflect recent efficiency and traffic trends.
Andrae (2020)	Further updated IP traffic and energy efficiency assumptions. Focuses on "Best" and "Expected" cases.	196-299 TWh in 2020 Projections: 204-412 TWh in 2025 366-974 TWh in 2030	Low-medium – similar to Andrae (2019).
IDTechEx			
IDTechEx (2025)	Methodology not disclosed in summary, but report includes market forecast of thermal design power of CPUs and GPUs.	150 TWh in 2015 Projections: 750 TWh in 2025 2400 TWh in 2035	N/A – cannot be assessed due to lack of methodological details.

Institution and publications	Summary	Results	Quality assessment
International Data Corporation (IDC)			
IDC (2023)	Methodology not disclosed in summary, but appears to be a bottom-up estimate based on server shipments and analysis by data centre type and workload (IDC, 2024b).	382 TWh in 2022 Projection: 803 TWh in 2027	High – uses bottom-up data and assumptions that reflect latest industry data and trends (IDC, 2024b).
Graham (2024)		320 TWh in 2022 Projection: 889 TWh in 2027	
IDC (2024c)	Includes AI-specific analysis	350 TWh in 2023 (of which 33 TWh AI) Projection: 857 TWh in 2028 (of which 146 TWh AI)	
International Energy Agency (IEA)			
IEA (2014)	Methodology not disclosed. Reproduces results from Van Heddeghem et al. (2014) until 2012 (270 TWh), but estimate is considerably higher than an assumed continuation of 4.4% growth in Van Heddeghem et al.	328 TWh in 2013	N/A – cannot be assessed due to lack of methodological details.
IEA (2017)	Global model based on an expansion of the US data centre energy model from Shehabi et al. (2016) and further updated for (Masanet et al., 2020)	194 TWh in 2014 Projection: 200 TWh in 2020	High – bottom-up estimate based on server and other IT shipments and stock and region-specific PUEs
4E EDNA (2019a)	Temporal extrapolation based on initial assumptions from IEA (2017), projected into the future based on expected traffic growth from DCs to end users, and on expected efficiency gains.	220 TWh in 2020	Low-medium – based on good initial assumptions but relies on temporal proxy extrapolation.
IEA (2019, 2020, 2021, 2022b, 2023b)	Hybrid estimate based on the bottom-up modelling in IEA (2017) and Masanet et al. (2020) and global estimates by Hintemann and Hinterholzer (2022) complemented with reported energy consumption data from large data centre operators.	200 TWh in 2018 200-225 TWh in 2019 200-250 TWh in 2020 220-320 TWh in 2021 240-340 TWh in 2022	High – combines base estimates from IEA (2017) and Masanet et al. (2020) with company-level trends and other credible analysis.
IEA (2024a)	Extrapolates and combines regional estimates and projections from government-affiliated reports from the US (Shehabi et al., 2016), Europe (Montevecchi et al., 2020), and China (Fan, 2021).	350 TWh in 2022 (460 TWh including crypto) Projection: 620-1 050 TWh in 2026 (including crypto)	Medium – uses older government estimates and projections from three largest data centre regions.
IEA (2024b); Spencer and Singh (2024)	2022 estimate from IEA (2023); methodology for projection not disclosed.	240–340 TWh in 2022 (excl. crypto) Projection: 515 TWh in 2030 (range 405-685 TWh, excluding crypto)	N/A – cannot be assessed due to lack of methodological details.
International Telecommunications Union (ITU); World Bank			
ITU (2020)	Based primarily on IEA (2017), supplemented by Malmodin and Lundén (2018), Shehabi et al. (2016) and Fuchs et al. (2017). 2030 projection based on Andrae (2019).	220 TWh in 2015 Projections: 230 TWh in 2020 411 TWh in 2030	High – 2015 and 2020 values rely on other high-quality studies.
World Bank & ITU (2024)	Analysis based on company-reported data of large colocation, cloud, and content data centre operators. Non-reporting companies are extrapolated based on revenue share of reporting companies.	195 TWh in 2022 from colocation (110 TWh), cloud (53 TWh), and content (32 TWh) data centres	Medium – high data quality but excludes enterprise data centres.

Institution and publications	Summary	Results	Quality assessment
Jeffries			
Jeffries (2024)	Combines regional aggregated data centre capacity estimates from various sources with extrapolation based on own assumptions (10-15% annual growth) and bottom-up estimate based on market-level data from industry and broker reports and press releases from hyperscalers. Results disaggregated by region.	319 TWh in 2020 418 TWh in 2022 524 TWh in 2023 Projections: 766 TWh in 2025 1 492 TWh in 2030	Medium – combines two approaches and various data sources.
Lawrence Berkeley National Laboratory (LBNL); Northwestern University; University of California Santa Barbara			
Masanet et al. (2020)	Bottom-up estimate based on shipment data for servers, drives, networking, their energy use characteristics and lifetimes, combined with assumptions for each type of data centre class and region-specific PUE.	194 TWh in 2010 205 TWh in 2018	High – detailed bottom-up analysis based on best available data with region-specific assumptions.
Liebreich Associates			
Liebreich (2025)	No methodology disclosed.	1.5% of current global electricity use (~400 TWh) Projection: 2.2% in 2030 (~750 TWh)	N/A – cannot be assessed due to lack of methodological details.
McMaster University			
Belkhir and Elmeligi (2018)	Extrapolates data centre energy use estimate for 2008 from Vereecken et al. (2010) increasing by 12% per year based on a market research company's projection to 2040.	704 TWh in 2017 Projections: 990 TWh in 2020 3 070 TWh in 2030 9 550 TWh in 2040	Low – simplistic temporal extrapolation based on trends from ~2010 which are assumed to continue to 2040.
Schneider Electric			
Schneider Electric (2021)	Bottom-up estimate based on workloads, data storage requirements, and global average PUE. Results split by compute, storage, and "DC infrastructures".	284 TWh in 2015 341 TWh in 2020 Projections: 429 TWh in 2023 719 TWh in 2030	Medium-high – uses bottom-up approach and assumptions.
Schneider Electric (2023)	Assumes AI power demand to grow at a CAGR of 25% to 33% until 2028.	500 TWh in 2023 (40 TWh for AI) Projection: 815 TWh in 2028 (122–165 TWh for AI)	N/A – cannot be assessed due to lack of methodological details.
Semianalysis			
Semianalysis (2024)	Detailed analysis based on analysis of over 3 000 colocation and hyperscale data centres in North America, construction and satellite data, and bottom-up shipment data and forecasts of AI accelerators.	375 TWh in 2022 Projection: 725-2 100 TWh in 2030	High – uses detailed data from a combination of sources and across multiple regions. Assumes relatively high utilisation rates and PUE which may overstate energy use.
TD Securities			
TD Securities (2024)	Bottom-up estimate based on projected shipments of AI accelerators and CPUs shipped, and replacement of existing equipment.	0.8% of global electricity use in 2018 (180 TWh) Projection: 2.9% of global electricity use in 2028 (~830 TWh)	Medium - uses some bottom-up data and modelling approaches

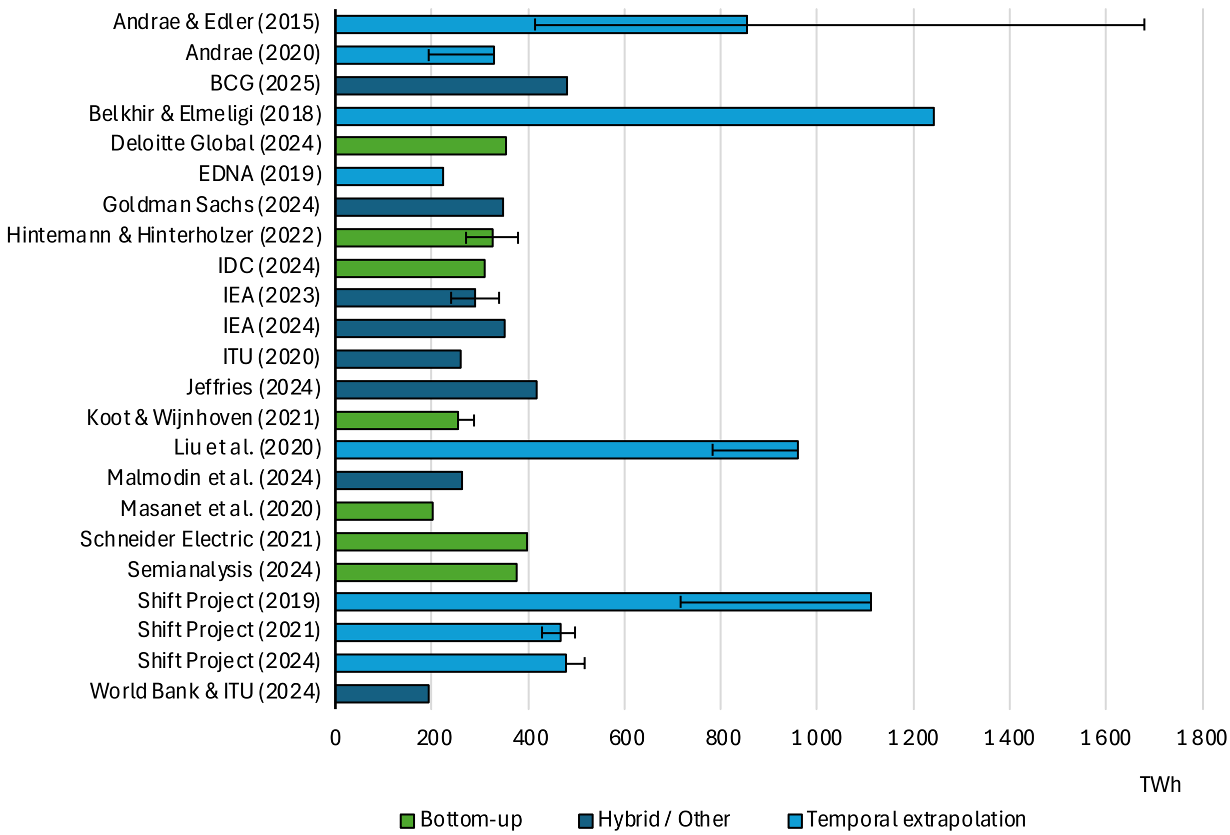
Institution and publications	Summary	Results	Quality assessment
Thunder Said Energy			
Thunder Said Energy (2025)	Temporal extrapolation based on extrapolated energy intensity of data centres (of all internet traffic).	800 TWh in 2022 Projections: 2 000 TWh in 2030 (of which 900 TWh for AI) 3 750 TWh in 2050	Low – simplistic temporal extrapolation using energy intensity of not just data centres but all internet traffic.
The Shift Project			
The Shift Project (2019)	Based on the model developed by Andrae & Edler (2015) with updated assumptions and scenarios.	559-593 TWh in 2017 Projections: 650-900 TWh in 2020 760-2040 TWh in 2025	Low – generally the same approach as Andrae & Edler (2015).
The Shift Project (2021)	Updates assumptions from the 2019 study.	393 TWh in 2019 (438 TWh including crypto) Projection: 560-740 TWh in 2025 (including crypto; non-crypto not specified)	Low-medium – same as above but reflects updated trends in technology development and efficiency.
The Shift Project (2024)	Updates assumptions from the 2019 and 2021 studies under three scenarios: Meta-métavers, Conservative, and Growth.	420 TWh in 2019 Projections: 556-656 TWh in 2025 771-1204 TWh in 2030	Low-medium – same as above but reflects updated trends in technology development and efficiency.
University of Twente			
Koot and Wijnhoven (2021)	Hybrid approach combining top-down indicators and bottom-up data (e.g. workloads per application).	286 TWh in 2016 240-275 TWh in 2020 Projections: 260-360 TWh in 2025 320-660 TWh in 2030	Medium – initial assumptions based on Masanet et al. (2020) but includes some temporal extrapolation of demand drivers.

Note: For projections that only state the share of global electricity use (rather than a total in TWh), the absolute electricity use is estimated based on projected electricity demand in the IEA World Energy Outlook 2024 Stated Policies Scenario (STEPS) (IEA, 2024b).

Source: Extends analysis from Kamiya and Bertoldi (2024) and UNCTAD (2024).

Focusing on estimates and projections for 2022, published estimates range from around 200 TWh to over 1 000 TWh (Figure 3.2). The highest values – and with the widest ranges in scenarios – come from studies that have used temporal proxy extrapolation approaches. It is also notable that some authors have significantly lowered their projections in more recent publications, with their latest values between 200–550 TWh for 2022 compared with 400–1 700 TWh in Andrae & Edler (2015) and 700–1 100 TWh in Shift Project (2019).

Figure 3.2 Selected estimates and projections of global data centre electricity use in 2022



Note: 2022 estimates as published or extrapolated from available data, except point estimate from Hintemann & Hinterholzer (for 2021). Values exclude energy use from cryptocurrencies. Error bars indicate range of scenario estimates for each study.

Sources: Andrae, 2020; Andrae & Edler, 2015; BCG, 2025; Belkhir & Elmeligi, 2018; Deloitte Global, 2024; EDNA, 2019a, 2019b; Goldman Sachs, 2024; IDC, 2024c; IEA, 2023b, 2024a; ITU, 2020; Jeffries, 2024; Koot & Wijnhoven, 2021; Liu et al., 2020; Malmodin et al., 2024; Masanet et al., 2020; Schneider Electric, 2021; Semianalysis, 2024; The Shift Project, 2019, 2021b, 2024; World Bank & ITU, 2024.

3.2 Regional and country-level estimates

This section reviews available regional and country-level estimates. Of the studies with global estimates on data centre energy use discussed above, only four – IDC, (2023), IEA (2024a), Jeffries (2024), Masanet et al. (2020) – present disaggregated results for multiple regional markets.

The review focuses primarily on the three largest data centre markets of United States, Europe, and China, which account for over 80% of data centres worldwide (Baxtel, 2024; Cisco, 2018; Cloudscene, 2024; Cushman & Wakefield, 2023; Data Center Map, 2024; DATACENTE.RS, 2024; Datacentres.com, 2024; Synergy Research Group, 2024a). One market intelligence firm estimates that the US accounted for around half of global hyperscale data centre IT capacity as of Q4 2023, followed by Europe (17%) and China (16%) (Synergy Research Group, 2024a).

3.2.1 United States

The most comprehensive bottom-up analyses of United States (US) data centre energy use have been led by researchers at the Department of Energy's Lawrence Berkeley National Laboratory (LBNL). In 2016, they estimated that data centres consumed 70 TWh in 2014 (1.8% of national electricity use) and could rise to 73 TWh by 2020 based on 'current trends' (Shehabi et al., 2016, 2018). These results are reflected in Masanet et al. (2020), which extends the LBNL analysis globally.

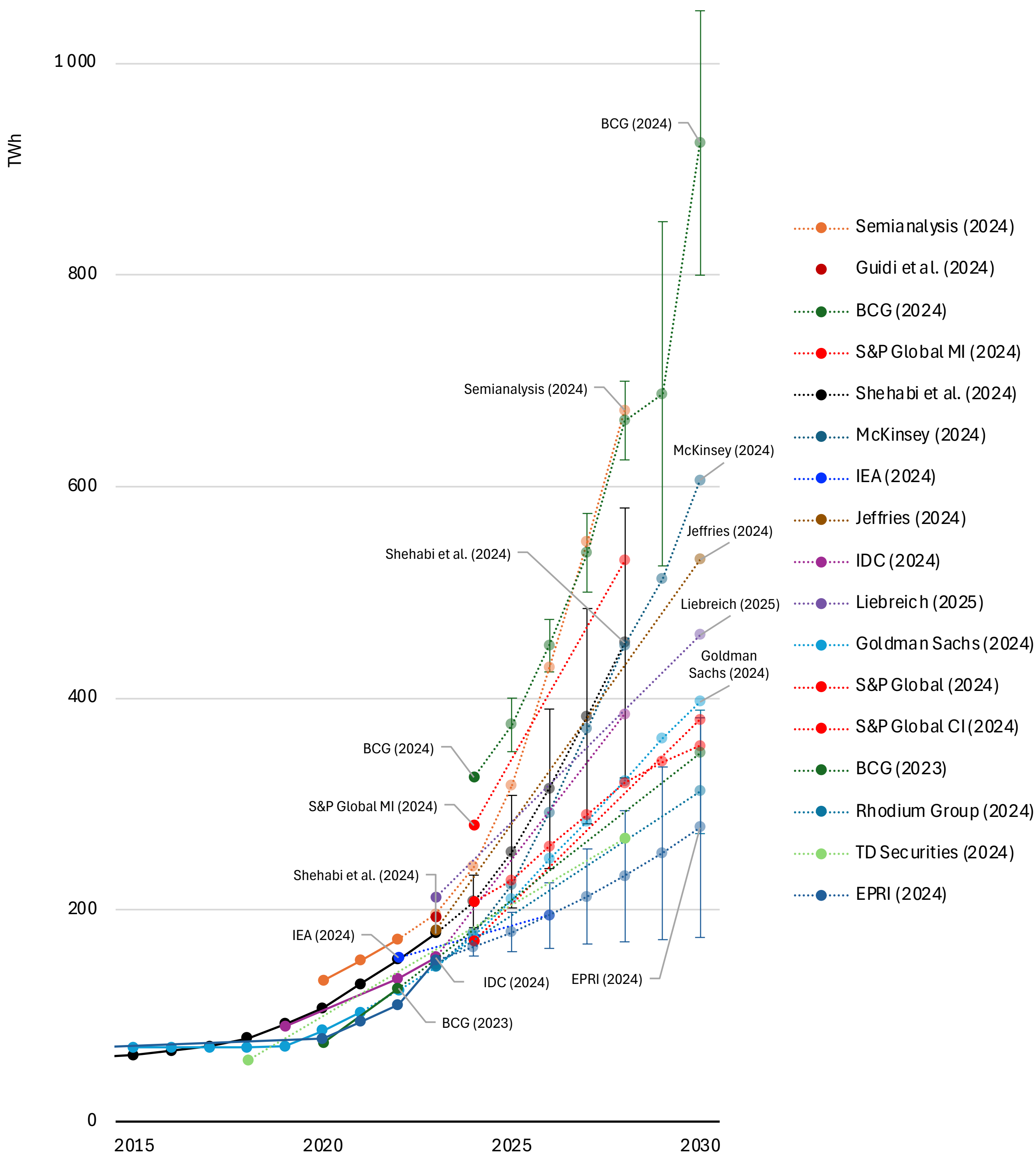
An updated study was published in December 2024, with estimated data centre energy use (excluding crypto) of 178 TWh in 2023 (4.4% of national electricity use), of which 40 TWh was consumed by AI-specialised servers (Shehabi et al., 2024). The report projects a range of 325–580 TWh in 2028 (of which 165–325 TWh for AI-specialised servers), equivalent to 6.7–12% of forecasted national electricity use in 2028.

With the rapid rise of AI and concerns about their impacts on energy use over the past two years, consultancies, investment banks, and industry associations have published estimates and projections of US data centre energy use. Some have significantly revised their estimates and projections, with projections for 2030 more than twice as high in the most recent reports. For example, McKinsey's January 2023 report projected data centre capacity of 35 GW in 2030, revised to nearly 60 GW (quoted in the Economist in January 2024), and to more than 80 GW in their latest September 2024 report – over two times higher than their initial projection from just 20 months earlier (McKinsey, 2023, 2024a; The Economist, 2024).

Boston Consulting Group (BCG) have also significantly revised both their current estimates and 2030 projections. In their September 2023 report, they estimated data centres in the US consumed 126 TWh for 2022, while their June 2024 report estimates data centres consumed nearly three times more in 2024 (325 TWh) – roughly in the range of their 2030 projection from the September 2023 report (BCG, 2023, 2024; Lee, 2023, 2024). Their 2030 projections more than doubled from 335–390 TWh in their September 2023 report to 800–1 050 TWh in their June 2024 report.

The results for the US studies are summarised in Figure 3.3 and detailed in Table 3.2.

Figure 3.3 US data centre energy estimates and projections, 2015-2030



Note: Darker circles indicate historical estimates; lighter circles and dotted lines indicate projections. Error bars indicate ranges included in scenarios. Values exclude cryptocurrencies.

Table 3.2 Overview of studies estimating the energy use of US data centres

Institution and publications	Summary	Results	Quality assessment
Boston Consulting Group (BCG)			
BCG (2023); Lee (2023)	Assumes 35-40% of current data centre energy use comes from US, based on share of DCs globally, but no source disclosed. Methods and assumptions for 2030 projections not clear.	74 TWh in 2020 126 TWh in 2022 Projection: 335–390 TWh in 2030 with GenAI	Low – based on a simplistic assumption of US share of global total.
BCG (2024); Lee (2024)	Unclear methodology. Appears to use bottom-up GPU supply data to estimate total power demand and power consumption. Low case constrained by current and planned DC infrastructure; high case is hardware constrained based on GPU supply.	325 TWh in 2024 Projections: 425–475 TWh in 2026 625–700 TWh in 2028 800–1 050 TWh in 2030	Low – appears to use the incorrect baseline figure for 2024 and assumed utilisation rates are too high (85-87%). Low range 2029 figure (525 TWh) appears to be a typo.
Electric Power Research Institute (EPRI)			
EPRI (2024)	Historical and baseline figures based primarily on LBNL model results (Koomey, 2011; Masanet et al., 2020; Shehabi et al., 2016, 2018). Projections based on differing assumed annual growth rates ranging from 3.7% (low growth) to 15% (higher growth) based on projected financial growth of data centres, 'expert assessment', and McKinsey projections.	152 TWh in 2023 Projections: 170–230 TWh in 2026 180–310 TWh in 2028 200–405 TWh in 2030	Low-medium – considers current DC electricity use at state level, but projects these into the future using the same growth rates across all states, despite the pace of growth is likely to be quite different.
Goldman Sachs			
Goldman Sachs (2024)	Global estimate based on initial high range of IEA estimate for 2022, Cisco workload projections, efficiency improvement trends of 3% in base case. Unclear how this is downscaled to US estimates.	146 TWh in 2023 (of which 4 TWh AI) Projection: 397 TWh in 2030 (of which 93 TWh for AI)	N/A – cannot be assessed due to lack of methodological details for US analysis.
Harvard University, University of Pisa, Environmental Systems Research Institute, Baxtel, UCLA			
Guidi et al. (2024)	Data on over 2,000 data centres from Baxtel (location and type), combined with available data on area and power capacities to model total power capacity. Assumes the same utilisation rate (75%) for all data centre types.	193 TWh in 2023	Medium – based on some site-level data but assumes a high utilisation rate (75%) which likely overestimates total energy use.
International Data Corporation (IDC)			
Graham (2024); IDC (2024a, 2024c)	Methodology not disclosed in summary, but appears to be a bottom-up estimate based on server shipments and analysis by data centre type and workload (IDC, 2024b).	90 TWh in 2019 ("Americas") 155 TWh in 2023 ("Americas") Projection: 385 TWh in 2028	High – uses bottom-up data and assumptions that reflect latest industry data and trends (IDC, 2024b).
International Energy Agency (IEA)			
IEA (2024)	Combines estimates from Shehabi et al. (2016) and blockchain energy use. Unclear method to extrapolate figures to 2022 and project to 2026.	200 TWh in 2022 (incl. crypto) Projection: 260 TWh in 2026 (including crypto)	Low-medium – detailed methodology not disclosed.
Jeffries			
Jeffries (2024)	Cites NextEra Energy citing McKinsey and projects 15% CAGR in data centre power demand between 2023 and 2030.	180 TWh in 2023 Projection: 530 TWh in 2030	Low-medium – lack of details regarding methodology but appears to be a temporal extrapolation.

Institution and publications	Summary	Results	Quality assessment
Lawrence Berkeley National Laboratory (LBNL); Northwestern University; University of California Santa Barbara			
Masanet et al. (2020); Shehabi et al. (2016, 2018)	Bottom-up estimate based on shipment data for servers, drives, networking, their energy use characteristics and lifetimes, combined with assumptions for each type of data centre class and region-specific PUE.	70 TWh in 2014 73 TWh in 2020 (current trends projection)	High – detailed bottom-up analysis.
Shehabi et al. (2024)	Similar methodology of previous studies, with updated input assumptions from IDC, Omdia, Dell'Oro, and S&P Global and in-depth analysis of AI-specialised servers.	178 TWh in 2023 (of which 40 TWh for AI-specialised servers) Projections: 185–230 TWh in 2024 (50–75 TWh for AI) 325–580 TWh in 2028 (165–325 TWh for AI)	High – detailed bottom-up analysis.
Liebreich Associates			
Liebreich (2025)	No methodology disclosed.	5% of current US electricity use (~200 TWh) Projection: over 9% in 2030 (~450 TWh)	N/A – cannot be assessed due to lack of methodological details.
McKinsey & Company			
McKinsey (2023)	No methodology disclosed. Mentions typical data centre uses 40% of its energy on cooling, i.e. implied PUE of 1.67.	17 GW capacity in 2022 19 GW capacity in 2023 Projection: 35 GW capacity in 2030	N/A – cannot be assessed due to lack of methodological details.
As cited in The Economist (2024)	No methodology disclosed.	20 GW capacity in 2022 22 GW capacity in 2023 24 GW capacity in 2024 Projection: 57 GW capacity in 2030	N/A – cannot be assessed due to lack of methodological details.
McKinsey (2024)	No methodology disclosed. Includes both assumed capacity and total electricity use.	147 TWh in 2023 178 TWh in 2024 (25 GW capacity) Projection: 606 TWh in 2030 (80 GW in 2030)	N/A – cannot be assessed due to lack of methodological details.
Rhodium Group			
Rhodium Group (2024)	Initial estimate based on literature review, and extrapolates three growth scenarios (low, mid, high) for data centres to 2030 and 2035.	~150 TWh in 2023 (estimated based on available information in Technical Annex) Projections: 2030: low (+85% from 2023), mid (+110%), high (+160%) – estimated to be 270/310/390 TWh in 2030 2035: low (+140% from 2023), mid (+180%), high (+260%) – estimated to be 350/410/540 TWh in 2035	N/A – cannot be assessed due to lack of details regarding the basis of the base year estimate and scenarios.

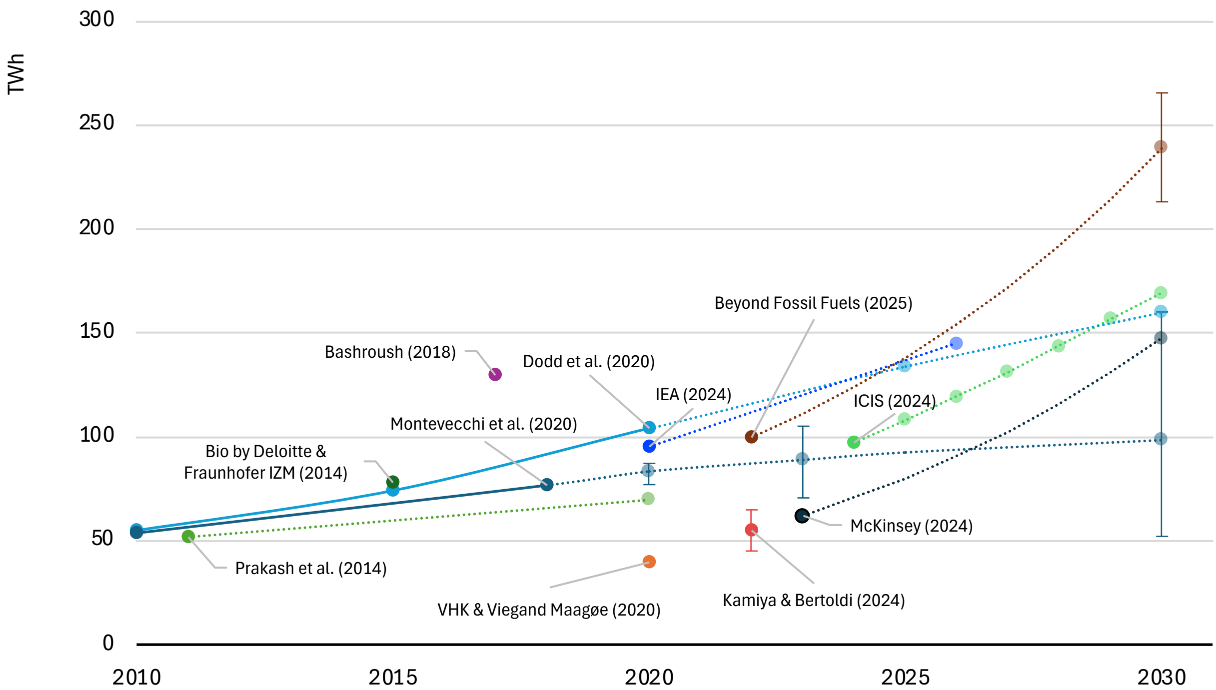
Institution and publications	Summary	Results	Quality assessment
Rystad Energy			
Rystad Energy (2024)	No methodology disclosed. Includes energy consumption by chip foundries.	140 TWh in 2024 (including semiconductor manufacturing) Projection: 307 TWh in 2030 (including semiconductor manufacturing)	N/A – cannot be assessed due to lack of methodological details.
S&P Global			
S&P Global Commodity Insights (2024)	Uses existing data centre load as a 'base' and adds incremental data centre load based on utility forecasts from regional electricity system operators.	185 TWh in 2023 Projections: 355-385 TWh in 2030 380-440 TWh in 2035	Medium –relies on utility forecasts but may include double-counted projects (requests to multiple grid operators) and excludes not yet submitted proposals.
S&P Global Market Intelligence (2024)	Appears to be based on planned data centre space and power consumption, presenting current (2023) and projected (2028) IT capacity by cluster.	Projections: Over 280 TWh in 2024 530 TWh in 2028	N/A – cannot be assessed due to lack of methodological details.
S&P Global (2024)	Reviews other projections of US data centre power demand increase from 2023 to 2030. Unclear how the authors' projections were developed.	170 TWh in 2024 Projection: 340-420 TWh in 2030 (7.5-8.75% of US electricity use)	N/A – cannot be assessed due to lack of methodological details.
Semianalysis			
Semianalysis (2024)	Bottom-up analysis based on analysis of over 3 500 existing and planned colocation and hyperscale data centres in North America, combined with other data.	133 TWh in 2020 196 TWh in 2023 Projection: 672 TWh in 2028	High – detailed bottom-up analysis.
TD Securities			
TD Securities (2024)	Bottom-up estimate based on projected shipments of AI accelerators and CPUs shipped, and replacement of existing equipment.	1.5% of US electricity use in 2018 (58 TWh) 6.6% in 2028 (~270 TWh)	Medium – uses some bottom-up data and modelling approaches.

3.2.2 Europe

Several studies have estimated European data centre energy consumption over the past decade, with wide-ranging results. For example, estimates for the European Union for 2020 range from 40 TWh to 104 TWh, while projections for 2030 range from around 50 TWh to 265 TWh (Figure 3.4).

The large range in these studies stems from substantial differences in data sources, assumptions, and methodologies, which are summarised in Table 3.3 and discussed in-depth in Kamiya & Bertoldi (2024). However, the lack of details and documentation regarding assumptions and methodology makes it difficult to compare underlying differences, and how they contribute to diverging estimates.

Figure 3.4 Summary of European Union data centre energy estimates, 2010–2030



Note: Darker circles indicate historical estimates; lighter circles and dotted lines indicate projections. Error bars indicate ranges included in scenarios. Values exclude cryptocurrencies.

Table 3.3 Overview of studies estimating the energy use of data centres in Europe

Author / Publication	Summary	Results	Quality assessment
Bashroush (2018)	Methodology not disclosed.	130 TWh in 2017	N/A – cannot be assessed due to lack of methodological details.
Beyond Fossil Fuels (2025)	Initial estimates for EU27 based on IEA (2024a) based on Montevecchi et al. (2020) with continuation of growth rates from IEA (2024a) to 2030 for "high demand" and from McKinsey (2024) for "low demand". UK estimates and projections based on National Grid ESO.	104-110 TWh in 2022 (EU27 + UK) Projection: 218-287 TWh in 2030 (EU27 + UK)	Low-medium – initial estimate for EU27 likely too high, combined with high growth rates to 2030 yields much higher projections for 2030 compared to original sources.
BloombergNEF et al. (2021)	Bottom-up estimate of colocation and hyperscale data centres based on data on installed data centre capacity in each country, public announcements, assumed rack capacities, and lease rates.	26 TWh in 2021 for Germany, Ireland, Netherlands, Norway, and the United Kingdom	Medium-high – high quality analysis but limited geographic scope and excludes small data centres.
Bio by Deloitte and Fraunhofer IZM (2014) *Prepared for DG GROW*	Bottom-up estimate based on detailed market data (e.g. server shipments) and informed hardware assumptions. The study also explores six scenarios over the period to 2030.	78 TWh in 2015 for EU28	High – detailed and comprehensive study using available market data.
Dodd et al. (2020) *Co-authored by the EC JRC Product Bureau and consultants*	Estimate based on data from 2013 data from DCD supplemented by surveys on data centre area, installed capacities, and other studies from the US and Europe including the Code of Conduct.	74 TWh in 2015 104 TWh in 2020 for EU27 Projections: 134 TWh in 2025 and 160 TWh in 2030	Low – based on outdated and limited data.

Author / Publication	Summary	Results	Quality assessment
ICIS (2024)	Initial (2024) estimates appear to be aligned with Kamiya & Bertoldi (2024), but not cited. No details on how future energy use is projected.	96 TWh in 2024 Projections: 168 TWh in 2030 and 236 TWh in 2035	N/A – cannot be assessed due to lack of methodological details.
IEA (2024a)	Hybrid estimate based on extrapolated values from Montevecchi et al. (2020) and country-level data and projections from Ireland and Denmark.	95 TWh in 2020 and 145 TWh in 2026	Medium – uses reliable studies for initial estimate but includes temporal extrapolation.
Kamiya and Bertoldi (2024) *Prepared by EC JRC*	Hybrid estimate combining country-level data centre energy use estimates where available, supplemented with other relevant and updated assumptions.	45-65 TWh in 2022	High – comprehensive and based on best available country-level data.
Masanet et al. (2020)	Bottom-up estimate based on stock and shipment data for servers, drives, networking, their energy use characteristics and lifespans, combined with assumptions for each type of data centre class and region-specific PUE.	39.4 TWh in 2018 for Western Europe	Medium – some assumptions based on US data and characteristics.
McKinsey (2024b)	Hybrid estimate based on initial 2023 estimates based on Kamiya & Bertoldi (2024) extrapolated with IT capacity projections from DCByte and proprietary McKinsey model.	62 TWh in 2023 for EU27+UK 150 TWh in 2030 for EU27+UK	Low-medium – solid basis for initial estimate, but uncertain data sources used in extrapolation.
Montevecchi et al. (2020) *Prepared for DG CONNECT by Environment Agency Austria and Borderstep Institute*	Bottom-up estimate based on data centre market developments, technical characteristics of servers, storage, and networking (energy use, age) and data centre infrastructure (air conditioning, power supply, UPS).	76.8 TWh in 2018 for EU28 (2.7% of EU28) Projections ("Trend" scenario): 92.6 TWh in 2025 and 98.5 TWh in 2030	Medium-high – uses detailed region-specific data.
Prakash et al. (2014) *Prepared for DG CONNECT by Öko-Institut and TU Berlin*	Bottom-up estimate based on server shipment data (and assumed server stock) and average assumptions for PUE, server utilisation rate, and share of IT energy for networking and storage.	52 TWh in 2011 Projection: 70 TWh in 2020	Medium-high – uses detailed data.
VHK and Viegand Maagøe (2020) *Prepared for DG ENER*	Based on Masanet et al. (2020).	39.5 TWh in 2020 for EU27	Medium – same as Masanet et al. (2020).

Source: Based on Kamiya & Bertoldi (2024) with additional studies published since January 2024.

In addition to estimates at the European Union level, there have been numerous country-level estimates published in recent years. These studies have been catalogued and reviewed in the most recent estimate prepared by the Joint Research Centre (JRC) in 2024, which estimated data centre energy consumption in the EU-27 in 2022 amounted to 45–65 TWh (Kamiya & Bertoldi, 2024). The study derived its estimate based on 15 country-level data centre energy use estimates supplemented with other relevant indicators and updated assumptions.

Three non-EU countries – the United Kingdom, Norway, and Iceland – also have notable data centre sectors. In the **United Kingdom**, its electricity system operator National Grid estimated that data centres used 4–7 TWh of electricity in 2020, equivalent to 1.3–2.5% of national electricity use (National Grid ESO, 2022). BloombergNEF estimates that colocation and hyperscale data centres in the United Kingdom used 7.2 TWh in 2021 (BloombergNEF et al., 2021). The most recent National Grid Future Energy Scenarios estimated that data centres used 3.5–5 TWh of electricity in 2023, or 0.4–0.5% of national electricity use (National Grid ESO, 2024). A recent study, based on assumptions from (Ademe & Arcep, 2022; Dodd et al., 2020; Montevecchi et al., 2020), estimated a much higher figure of 13 TWh (4% of national electricity), while acknowledging the data sources are of low to medium confidence (Lannelongue et al., 2024). In June 2024, National Grid CEO John Pettigrew projected that data centre energy use would increase six-fold over the next decade, driven by AI and quantum computing (BBC, 2024; Pettigrew, 2024). The underlying projections from National Grid indicate that data centres could use 10–22 TWh in 2030, or 1–2% of national electricity use in 2030 (National Grid ESO, 2024).

In **Norway**, the Norwegian Water Resources and Energy Directorate (NVE) estimate that data centres in Norway consumed 1.5 TWh in 2023 (1.1% of national electricity) (NVE, 2024). The report projects data centres to consume 3.5 TWh in 2028 (2.3%). BloombergNEF estimates that colocation and hyperscale data centres in Norway used 0.7 TWh in 2021 (BloombergNEF et al., 2021).

In **Iceland**, the National Electricity Regulatory Authority estimates that data centres accounted for 1.1 TWh in 2023 (5.5% of national electricity) and 1.4 TWh in 2024 (6.7%) (Orkustofnun, 2024). By 2050, data centre energy use is projected to grow to 3.3 TWh (12.5% of national electricity use) in the "Business as Usual" scenario and 6 TWh (15%) in the "High Forecast" scenario.

3.2.3 China

In China, there have been several published estimates of data centre energy consumption over the past five years, with estimates in the range of 150–270 TWh for 2020 to 2023 (China Academy of Information and Communications Technology, 2023; Fan, 2021; Greenpeace East Asia, 2021; Greenpeace East Asia & North China Electric Power University, 2019; Jeffries, 2024; Li et al., 2024). While some studies note that these figures include 5G networks, the lack of details regarding methodologies and scope make it unclear whether 5G mobile networks (or data networks in general) are included within the scope of these figures. A recent article from the Development Research Center of the State Council (2024), citing the China Academy of Information and Communications Technology (CAICT), stated that the national digital industry consumed 370 TWh in 2022, with data centres accounting for 76.6 TWh.

An in-depth analysis by IEA published in February 2025 estimated that data centres in China likely consumed 70–130 TWh of electricity in 2023, with data transmission networks (including 5G) consuming another 100 TWh (IEA, 2025). The analysis relied on published energy consumption data reported by many of the largest Chinese data centre operators, along with bottom-up modelling of hardware shipments. The report also projects data centres in China could consume 180–340 TWh in 2027 and 260–470 TWh in 2030.

Other organisations have previously also published projections, most in the range of 300–400 TWh by 2030 (CAICT, 2023; Fan, 2021; Li et al., 2024; Open Data Center Committee, 2022; Xie et al., 2024). Others have projected much higher figures, including the Chinese Electronics Standardisation Institute (600 TWh by 2030) investment bank Jeffries (1 000 TWh by 2030) (CESI, 2022; Jeffries, 2024).

3.2.4 Other countries and regions

In **Japan**, data centres account for 10–20 TWh, or 1–2% of national electricity consumption (CRIEPI, 2024; Deloitte Tohmatsu MIC Research Institute, 2022; Japan Atomic Industrial Forum, 2024; Nikkei, 2022). The Central Research Institute of Electric Power Industry (CRIEPI) recently projected that data centre energy use could rise to around 40–110 TWh by 2040 and 45–210 TWh by 2050 (CRIEPI, 2024; Take, 2024).

In **Australia**, data centres currently use an estimated 8–12 TWh (3–5% of national electricity use) according to investment banks Morgan Stanley and UBS (Hannam, 2024; Kitchen, 2024). Both banks project a rapid increase to 2030, with UBS projecting a more than doubling to 28 TWh by 2030, while Morgan Stanley projects a range of 14–43 TWh.

In **India**, data centres consumed around 2 TWh in 2014, or 0.2% of national electricity use (IEA, 2017). The IEA projected this could grow to around 3 TWh by 2020. Investment bank Jeffries estimated data centres used 6–9 TWh in 2023 and projected a 12-fold growth in data centre capacity to 17 GW by 2030, with data centres projected to use 6% of national electricity use (Jeffries, 2024). A November 2024 report from investment bank Nomura estimates that data centres currently consume 8.4 TWh of electricity (0.5% of national electricity use) and projects this to grow to 66 TWh by 2030 in its base case (3% of national electricity use) and 80 TWh in its bull case (Nomura, 2024). These figures correspond to assumed installed capacities of 960 MW today and 7.5 GW and 9 GW in 2030, roughly half of Jefferies' 2030 projections (17 GW). Cushman & Wakefield projects colocation data centre capacity of 5 GW by 2028 (Vij, 2024).

In **Singapore**, data centres accounted for 3.4 TWh, equivalent to around 7% of national electricity consumption in 2020 (Singapore Ministry of Communications and Information, 2021). The latest energy statistics show that the "Information and Communications" subsector (which likely includes data centres and data transmission networks), accounted for 4.9 TWh in 2022 (8.8% of national electricity use), 5.4 TWh in 2023 (9.8%), and 2.9 TWh over the first half of 2024 (10.3%) (Singapore Energy Markets Authority, 2023, 2024). This means that the ICT subsector has accounted for nearly half of the net growth in national electricity consumption, growing at an average compound annual rate of 18% since 2020 compared with less than 2% for all other subsectors. Subtracting electricity consumption from telecommunication networks (0.4 TWh based on company data), data centres consumed around 5 TWh in 2023. An industry report from 2021 projected that data centres would account for 12% of national electricity use by 2030 (Bain et al., 2021).

Other significant and growing data centre markets in Asia include **South Korea** and **Malaysia**, with 0.7–1.3 GW and 0.4 –0.7 GW of data centre capacity respectively (Cushman & Wakefield, 2024; Kerner, 2024; Savills, 2024b, 2024a). There have not been any public estimates of data centre energy consumption in either country. Based on the estimated capacities above, data centres likely consume 3–5 TWh in South Korea and 2–3 TWh in Malaysia.

In **Canada**, data centres likely consume 3–6 TWh, equivalent to 0.5–1% of national electricity use (Government of Canada, 2024; Natural Resources Canada, 2013). According to the Royal Bank of Canada, current data centre capacity is 750 MW and with over 14 GW of capacity proposed to electricity regulators by 2030 (Merwat, 2024).

In Ontario, the largest market, the transmission system operator IESO has projected that data centres could consume 8.4 TWh by 2035 (4% of projected provincial electricity demand) (IESO, 2024). In the second largest market of Quebec, data centres consumed around 1.3 TWh in 2023 with projected growth of 4 TWh to 2032 (Energyzt, 2022; Hydro-Québec, 2022).

In **Latin America**, the largest data centre markets of Brazil, Chile, and Mexico have a combined IT capacity of around 700 MW (White & Case LLP, 2024), likely accounting for around 2–3 TWh of electricity use annually.

In **Africa**, the vast majority of the 300 MW of data centre capacity today is located in South Africa, Kenya, and Nigeria (African Data Centres Association, 2024). data centres consumed 1–2 TWh in 2020, projected to rise to 5–8 TWh by 2030 (IEA, 2022a; Open Access Data Centres (OADC), 2023; Xalam Analytics, 2022).

In the **Middle East**, the United Arab Emirates and Saudi Arabia have the largest data centre sectors, each with around 300 MW of capacity (Cushman & Wakefield, 2025; Roland Berger, 2024).

3.3 Artificial intelligence

3.3.1 AI energy use

One of the biggest drivers of near-term growth in data centre energy consumption stem from the rapid growth of artificial intelligence (AI) – particularly generative AI applications such as ChatGPT.

Early studies on the energy and carbon footprint of AI and machine learning (ML) focused on the energy and carbon emissions associated with *training* large language models (Lacoste et al., 2019; Luccioni et al., 2020; Schwartz et al., 2019; Strubell et al., 2019). But training a single ML model represents only a small fraction of the overall energy use of AI. Data from Meta (Wu et al., 2022) and Google (Patterson et al., 2022) indicate that the *training* phase accounts for around 20–40% of overall ML-related energy use, with the majority (60–70%) from *inference* (application/use). Less than 10% is attributed to model *development* (experimentation).

As mainstream adoption of generative AI increases, the share of inference in overall AI energy use is expected to grow (Schneider Electric, 2023). As new generations of smartphones and laptops incorporate AI capabilities (e.g. Apple Intelligence), a growing share of AI inference workloads are likely to be handled by devices rather than data centres (Kamiya & Kaack, 2024).

Aggregating for the entire company, Google researchers estimated that ML accounted for 10–15% of company-wide energy use in the years prior to 2022 (i.e. 2–3 TWh in 2021), noting that it was growing at a similar rate as overall company-wide energy use – around 20–30% per year (Google, 2023; Patterson et al., 2022).

3.3.2 AI energy use in data centres

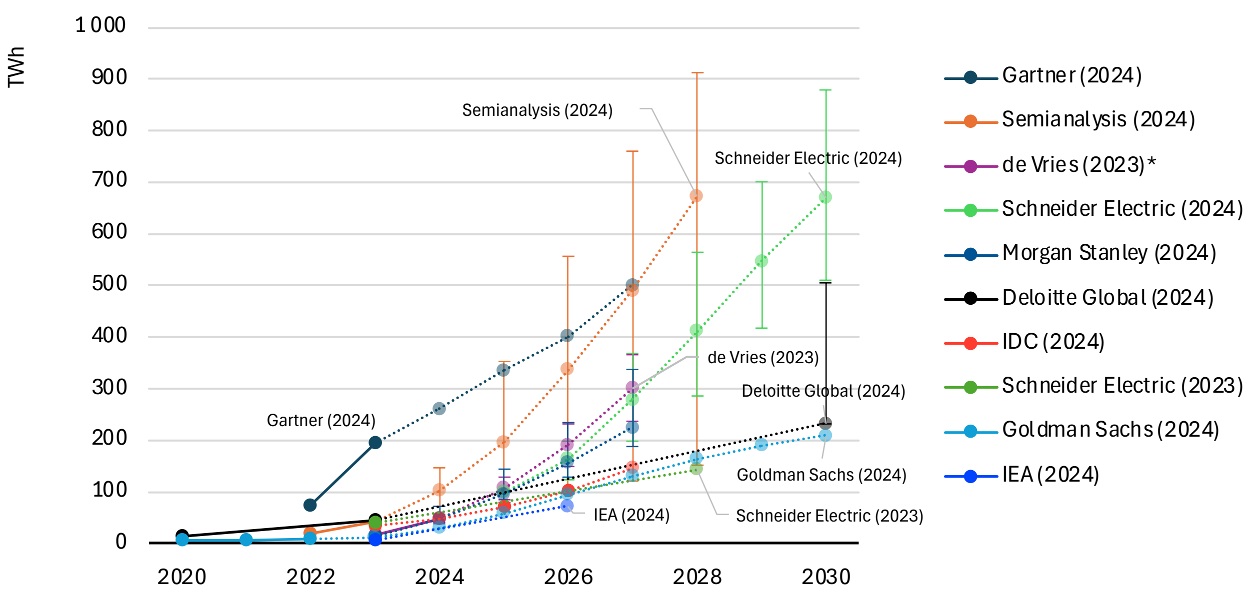
One of the first global estimates of AI energy consumption in data centres was published in October 2023 (de Vries, 2023). Based on estimated Nvidia's GPU sales, de Vries (2023) estimated that GPUs produced in 2023 could consume 5.7–8.9 TWh annually and those projected to be produced in 2027 could consume 85.4–134 TWh. The study includes assumptions that overestimate AI energy use (100% utilisation rate is too high) and underestimate AI energy use (excludes non-Nvidia GPU and AI accelerators and already produced AI accelerators).

Based on de Vries (2023) but likely misinterpreting the annual growth for 2023 and 2027 as absolute consumption values for those years, IEA (2024a) projects AI energy consumption of 90 TWh in 2026. The same misinterpretation of de Vries (2023) appears in a recent article in *Nature* (Luers et al., 2024).

Other recent projections have used similar modelling approaches to develop projections to 2030, using bottom-up estimates based on the power consumption of GPUs and their projected shipments. Projected shipments are often based on a combination of manufacturer projections, expert interviews, and macroeconomic trends. Schneider Electric (2024) represents an exception, being based on a top-down quantitative systems dynamics approach.

The results of global studies estimating the energy use of AI in data centres are shown in Figure 3.5 and summarised in Table 3.4. Due to most studies not providing sufficient detail regarding their methods, and the challenges in assessing quality in an emergent and rapidly evolving field of study, we do not provide a quality assessment level.

Figure 3.5 Selected global AI energy use projections, 2020-2030



Notes: Darker circles indicate historical estimates; lighter circles and dotted lines indicate projections. Error bars indicate ranges included in scenarios. de Vries (2023) totals based on linear interpolation between the study's assumed 2023 and 2027 production of AI accelerators, to calculate cumulative energy consumption (i.e., each year's newly built AI accelerators add to the consumption of existing stock).

Table 3.4 Overview of studies estimating the global energy use of AI

Author / Publication	Summary	Results	Quality assessment
de Vries (2023)	Bottom-up based on current (2023) Nvidia GPU sales and a projection based on estimated GPU production increases by 2027.	6–9 TWh *growth* in 2023 accelerating to 85–134 TWh *growth* by 2027 Linearly interpolating growth yields a *consumption of* 14–17 TWh in 2023, and 236–365 TWh in 2027	Solid 2023 growth estimate; does not state a starting value (i.e., for 2022). Assumptions behind accelerating growth undisclosed.
Deloitte Global (2024)	Bottom-up based on data from IDC (2024a, 2024c). Baseline scenario assumes AI adoption in cost-efficient applications. High adoption scenario assumes current growth trends in AI servers to continue.	45 TWh in 2023 230 TWh in 2030 (500 TWh in High adoption) 350 TWh in 2035 (1 000 TWh in High adoption)	Reflects industry data and projections of server shipments to 2030. Projections beyond 2030 rely on logistic growth rates which may differ for AI.
Gartner (2024a, 2024b)	Methodology not disclosed, likely based on vendor surveys and market feedback. Expects sharp rise from 2023 to 2024 and then more moderate growth by 2027 due to power availability constraints for DCs.	74 TWh in 2022 195 TWh in 2023 500 TWh in 2027	Could not be assessed due to a lack of methodological details.
Goldman Sachs (2024)	Bottom-up based on historical trends and projected GPU and specialised hardware adoption rates together with projected DC CapEx.	12 TWh in 2023 (of which 4 TWh in the US) 209 TWh in 2030 (of which 93 TWh in the US)	Future extrapolation based on a variety of economic values; expectations which, however, can be subject to rapid change.
IDC (2024c)	Bottom-up estimate based on server shipments and analysis by data centre type and workload (IDC, 2024b).	33 TWh in 2023 146.2 TWh in 2027	Reflects industry data and projections of server shipments.
IEA (2024)	Based on de Vries (2023) but likely misinterpreting the annual growth rate as absolute consumption.	5 TWh in 2022 90 TWh in 2026	Likely misinterpreting the results from de Vries (2023).
Morgan Stanley (2024)	Scenario-based future AI adoption rates, and thus workload growth forecasts. For each of the bear, base and bull scenarios, “high” and “low” values (for 4-chip and 8-chip servers, respectively).	Base case (Bear to Bull range): 13.2 TWh in 2023 (11–20 TWh) 47.55 TWh in 2024 (40–71 TWh) 224.3 TWh in 2027 (187–336 TWh)	Considers important factors and expert opinions, but uncertainties are high.
Schneider Electric (2023)	Bottom-up estimate of current (2023) AI energy consumption; forecast based on internal growth projections	4.5 GW (39 TWh/year) in 2023 14–18.7 GW (123–164 TWh) in 2028	Exact method undisclosed. Appears to be based on domain understanding and taking into account many developments and constraints.
Schneider Electric (2024)	Quantitative systems dynamics (QSD) exploring four archetypal exploratory scenarios. Covers dozens of factors. modelled in a core QSD model, with sub-models focusing on training and inference of specific AI types.	100 TWh in 2025 growing in the four scenarios by 2030 to: 620 TWh (“Sustainable AI”) 510 TWh (“Limits to growth”) 880 TWh (“Abundance without boundaries”) 670 TWh (“Energy crunch”) – in this scenario, crunch appears from 2031 on.	Very detailed top-down method, which succeeds at covering a wide range of possible applications. Exact factors remain undisclosed and constraints might be underrepresented.
Semianalysis (2024)	Detailed analysis based on a combination of bottom-up data (hardware shipments, power requirements by model), market data on current and future capacity of large operators, and other data (e.g. permits, satellite data).	20 TWh in 2022 30–50 TWh in 2023 (~40 TWh base case) 80–350 TWh in 2025 (~200 TWh base) 150–900 TWh in 2028 (~650 TWh base)	Very robust and detailed analysis combining multiple types and sources of data.

Several studies have estimated the energy use of AI servers in the United States. Shehabi et al. (2024) estimate that AI-specialised servers in the US accounted for less than a quarter (22%) of total data centre energy use in 2023 (40 TWh) and projected this share to rise to 50–55% by 2028 (165-325 TWh). Researchers at the Center for Strategic and International Studies (CSIS) estimated AI data centres in the US consumed 4 GW in 2024 (~35 TWh), and projected this to rise 20-fold by 2030 to 84 GW (~735 TWh) (McGeady et al., 2025). Another recent study published by RAND Corporation projected AI data centre capacity could grow to 327 GW by 2030 – a 30-fold growth from 2024, and equivalent to two-thirds of current US electricity consumption (RAND, 2025).

The domain is so recent that not even its system boundaries are well-defined (Masanet et al., 2024). Some of the sources only consider GPUs from one manufacturer (Nvidia), while others consider all hardware for accelerated computing, such as GPUs from other manufacturers and other AI accelerators such as TPUs. Others may also consider some share of CPUs used for inference. There are also questions of whether a share of end-user devices count as well towards the energy and environmental impact of AI, given the growing role of AI inference on end user devices such as smartphones.

3.3.3 AI projections to 2030

The plausibility of an upper-bound AI energy projection to 2030 can be assessed based on conservative assumptions of costs and power consumption of GPUs. The B100 GPU is estimated to cost around USD 30–35k (Trueman, 2024) and has a thermal design power (TDP) of 700 W (Nvidia, 2024). We conservatively assume similar costs for the more performant Nvidia Blackwell B200, with a TDP of 1 000 W (Nvidia, 2024).

Further conservative assumptions include a utilisation rate of 100% for all GPUs and AI hardware ever sold and that energy consumption at peak workload equals the TDP. Both assumptions are highly conservative, given actual peak workload power represented a much lower 37 – 72.3% of TDP in one study (Govind et al., 2023).

Every 100 TWh of yearly AI data centre energy consumption correspond to 11.4 GW of average power over the entire year. This would require 11.4 million Nvidia Blackwell B200 GPUs running in parallel for the entire year at 100% utilisation rate and peak workload power equal to TDP (our conservative assumptions). Assuming a unit cost of USD 30k this would require an investment of over USD 340 billion in GPUs alone for every 100 TWh of additional yearly AI consumption in data centres.[2]

This means that USD 500 billion in AI investments, announced as a target of the US government over the next 5 years, would consume 146 TWh annually if all investments went to GPUs and other AI accelerators. This upper-bound estimate excludes other costs, many of which are substantial (e.g., the construction of the data centres themselves, electricity, wages) and may be included in the USD 500 billion target.

If the US accounts for about half of the world's AI computing – similar to its share of hyperscale data centres – this implies a global investment of about USD 1 trillion AI investment and 300 TWh in AI DC consumption in 2030.

[2] More realistic assumptions (i.e., utilisation rate below 100% and peak energy lower than the TDP) would require a correspondingly higher investment to reach the same yearly consumption of 100 TWh.

The higher-end estimates of 700–900 TWh would imply meeting several unlikely conditions:

- cumulative capital expenditures to 2030 of over 2 trillion USD in accelerated hardware (such as GPUs or TPUs), excluding other capital expenditures and ongoing operational costs such as electricity and wages,
- 100% utilisation of all chips ever produced and that peak workload power equals TDP,
- no other technological, resource (energy, water) or societal constraints.

We thus consider these higher-range values to be unrealistic. Based on the best available information today, we project AI energy use in data centres is likely to reach 200–400 TWh in 2030 – in line with the lower range of projections in Figure 3.5.

4. Estimating the energy use of data centres

This chapter describes how the outcomes of the critical review and analysis are used to inform and develop our own estimates of data centre energy use from three perspectives: global, country-level, and company-level.

4.1 Modelling methodology

In Chapter 3, we comprehensively and critically reviewed the existing literature on data centre energy use, including our quality assessment of each study.

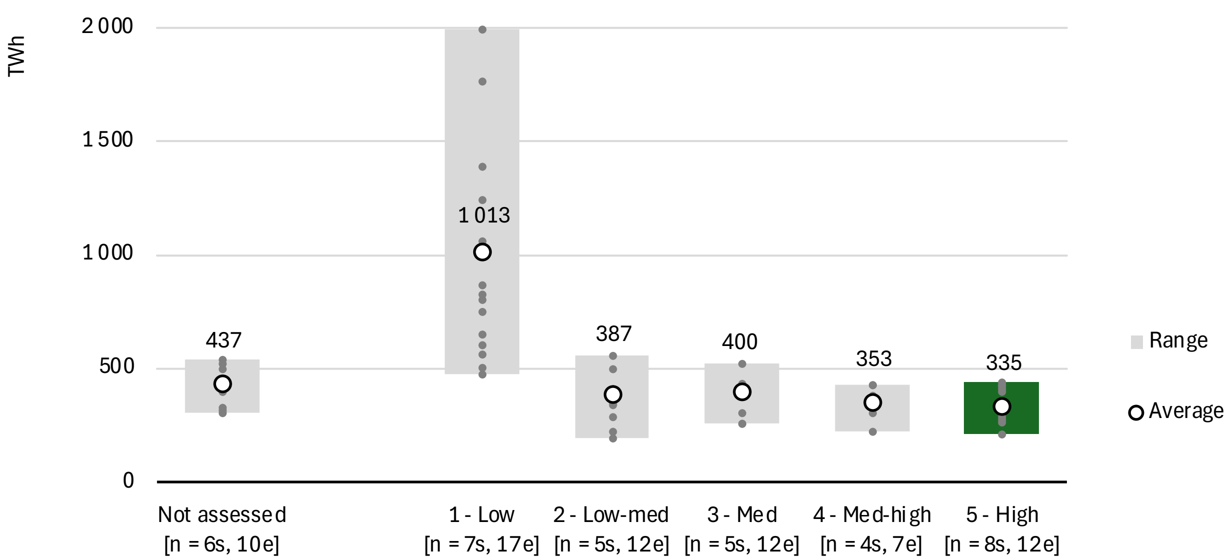
We focus on the results of studies that we rated as "high" – those with a high degree of methodological rigour and transparency. If estimates for 2023 were not available, an estimate for 2023 was interpolated or extrapolated based on estimates for other years.

We then combined the best available country and regional-level estimates with best available estimates at the global level to provide a plausible range of global data centre energy estimates for 2023. Company-level data is also analysed to provide a lower bound estimate for cloud and hyperscale data centres.

4.2 Global estimates

Our review of global estimates shows that seven high-quality studies (covering 11 estimates) with estimates for 2023 had a range of **210–440 TWh with an average base case estimate of 335 TWh** (Figure 4.1).

Figure 4.1 Estimates of global data centre energy use in 2023, by assessed quality



Notes: Range of estimates include all scenarios, while average values are for base cases only. Numbers in parentheses indicate the number of studies (s) and estimates (e). "Not assessed" are studies that did not share sufficient methodological detail to assess their quality.

4.3 Regional and country-level estimates

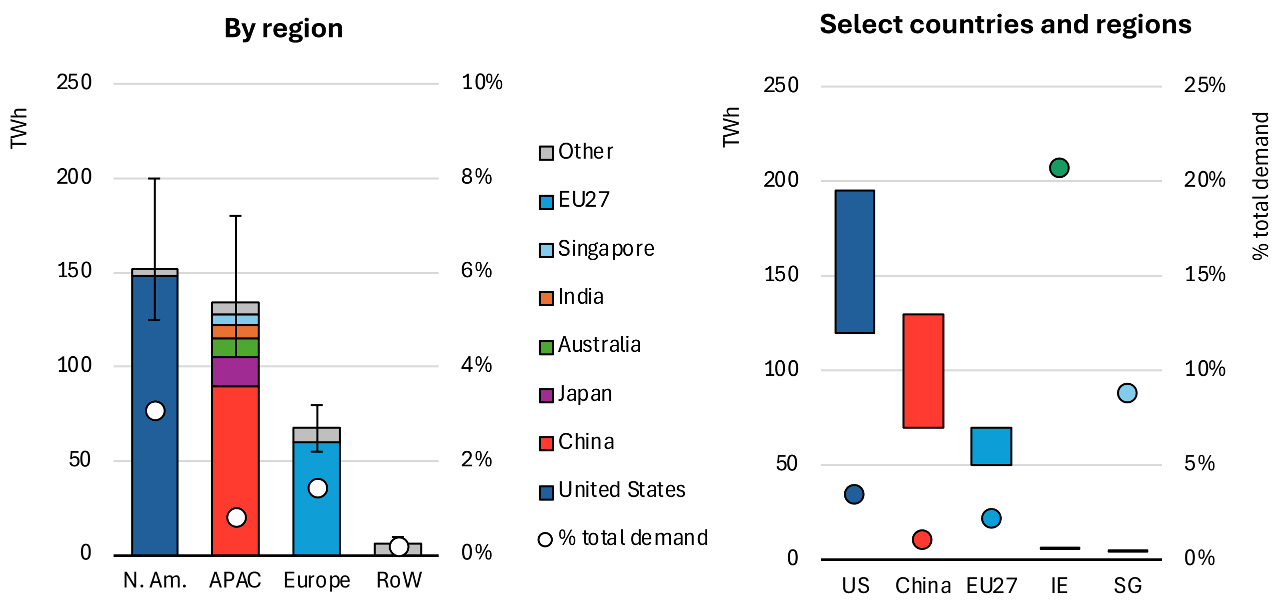
At the regional level, we estimate that data centres consumed:

- **125–200 TWh in North America** (including 120–195 TWh in US and 3–6 TWh in Canada)
- **105–180 TWh in Asia Pacific** (including 70–130 TWh in China, 10–20 TWh in Japan, 8–12 TWh in Australia, 6–9 TWh in India, 5 TWh in Singapore, 3–5 TWh in South Korea, and 2–3 TWh in Malaysia)
- **55–80 TWh in Europe** (including 50-70 TWh in EU27, 4–8 TWh in UK, 1–2 TWh in Norway, ~1 TWh in Iceland)
- **5–10 TWh in other regions** (including 2 –3 TWh in Latin America and 1–2 TWh each in Africa and the Middle East).

This implies that using best available country and regional-level estimates, **data centres globally consumed 290–470 TWh in 2023, with a central estimate of 360 TWh.** The US (41%), China (25%), and Europe (19%) accounted for 85% of the global total (Figure 4.2, left).

Based on this analysis, data centres in the US accounted for around 3.5% of national electricity demand in 2023, compared with 2.2% in the EU27 and around 1% in China (Figure 4.2, right). The highest share of national electricity demand from data centres was in Ireland (21%) and Singapore (9%).

Figure 4.2 Data centre electricity use and share of total electricity consumption by region (left) and for select countries and regions (right)



Notes: N. Am. = North America. APAC = Asia Pacific, including Oceania. RoW = rest of world, including Latin America, Africa, and the Middle East. EU27 = European Union 27. IE = Ireland. SG = Singapore.

4.4 Aggregated company-level data

Many of the largest data centre operators report their annual company-wide energy use and greenhouse gas emissions data through their corporate sustainability reports and to CDP. While some of these companies also have major non-data centre business divisions such as telecommunication networks, retail stores, warehouses, and offices that use electricity, in most cases, the majority of electricity used by large data centre operators are consumed in data centres, making company-wide trends a useful proxy for data centre energy use trends.

While most of the largest data centre operators publicly disclose company-wide electricity use, only a select few have disclosed detailed information about electricity used by their data centres (Masanet et al., 2024). Apple, Meta, and Salesforce disclosures show that data centres accounted for 67%, 98%, and 94% of company-wide electricity use in 2023 respectively (Apple, 2024; Meta, 2024; Salesforce, 2024). Where possible, proxy data were used to estimate the share of data centre electricity as a share of company-wide electricity (e.g. Scope 2 emissions from data centres as a share of total Scope 2 emissions for the company, combining reported water consumption and WUE). For years where data were not disclosed, estimates were extrapolated based on trends of available years, as well as energy intensity factors (revenue per kWh).

Aggregating company-wide electricity consumption data from 60[3] large data centre and technology companies results in a combined company-wide total of 320 TWh in 2023, of which data centres consumed around 200 TWh (63%) (Figure 4.3).

Company-wide electricity use of the four largest data centre operators – Amazon, Alphabet (Google), Microsoft, and Meta (Facebook) – more than tripled between 2018 and 2023 from around 35 TWh to over 110 TWh. We estimate that data centres likely accounted for around 80% of the combined company-wide total for these four hyperscalers in 2023, or around 90 TWh.

Colocation data centre operators are also large energy users. For example, Digital Realty (11.1 TWh), Equinix (8.2 TWh), CyrusOne (4.2 TWh), QTS (2.6 TWh), Vantage Data Centers (2.6 TWh), and EdgeConneX (1.3 TWh) collectively accounted for 30 TWh of electricity use in 2023. While these companies are headquartered in the US, they operate data centres globally.

In China, tech companies Alibaba (8.3 TWh), Huawei (5.6 TWh), Tencent (5.1 TWh), JD.com (1.8 TWh), and Baidu (1 TWh) used around 22 TWh, while colocation operators GDS (5.4 TWh), Chindata (3 TWh in 2022), and VNET (1.3 TWh) accounted for nearly 10 TWh. The three major telecommunication operators in China are also large data centre operators, with data centres likely accounting for around one-quarter of total company-wide electricity (27 TWh out of 110 TWh). In total, we estimate that data centres of companies headquartered in China accounted for around 56 TWh of electricity use (most but not all consumed in China).

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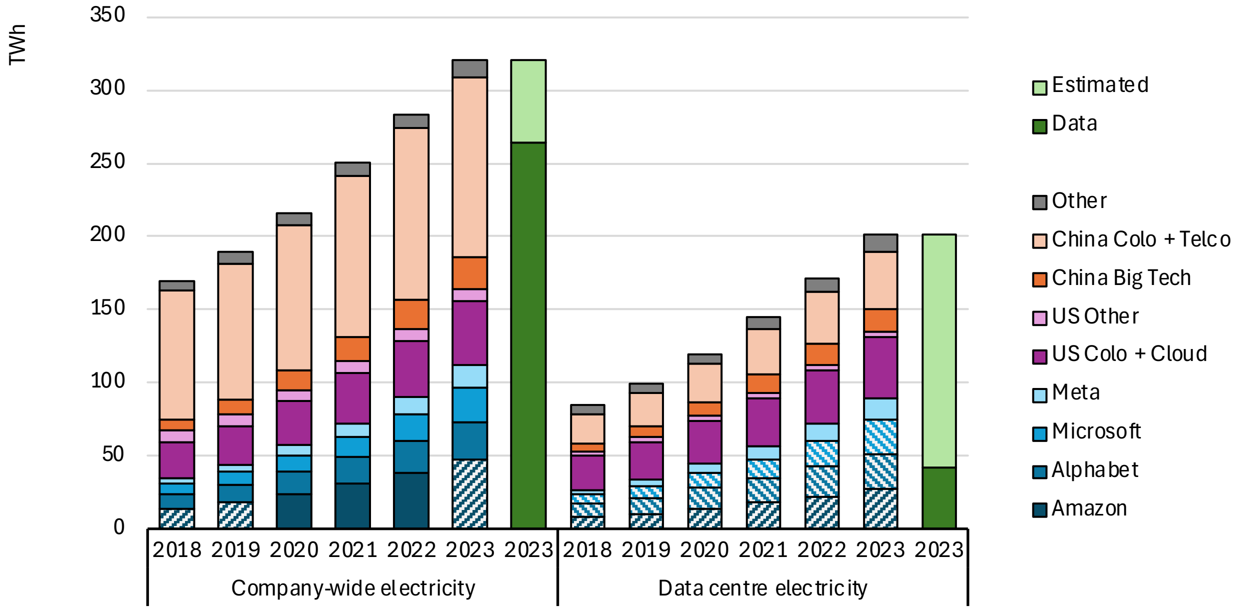
[3] Airtrunk, Akamai, Alibaba, Alphabet (Google), Amazon, Apple, Ascenty, Baidu, China Mobile, China Telecom, China Unicom, Chindata, Cloudflare, Cologix, Colt DCS, COPT, CoreSite, CyrusOne, Databank, Digital Edge, Digital Realty, EdgeConneX, Equinix, Flexential, GDS, Global Switch, Green Mountain, Huawei, IBM Cloud, Iron Mountain, JD.com, Kakao, Kao Data, KDDI Telehouse, Keppel DC REIT, Kingsoft Cloud, Kuaishou Technology, LG CNS, Lumen, Meta (Facebook), Microsoft, Naver, Netflix, NextDC, NTT Data, Oracle, OVH Cloud, QTS, Rackspace, Sabey, Salesforce, SAP, ST Telemedia, SUNeVision, Switch, Tencent, Vantage, VNET (21Vianet), Xiaomi, Zayo.

Figure 4.3 **Estimated electricity use by large data centre operators and technology companies, 2018–2023**



Notes: Striped data for companies indicate authors' own estimates due to a lack of publicly reported data; estimates based on other available data on energy, emissions, and revenue. "US Colo + Cloud" includes colocation and cloud companies headquartered in the United States, including Digital Realty, Equinix, CyrusOne, QTS, Vantage, and Oracle. "China Big Tech" includes tech companies headquartered in China, including Alibaba, Baidu, Huawei, JD.com, Kuaishou Technology, Tencent, and Xiaomi. "China Colo + Telco" includes large colocation operators including GDS, Chindata, and VNET, as well as the three largest Chinese telecommunication operators China Mobile, China Telecom, and China Unicom.

Sources: Own analysis based on company ESG reports, CDP disclosures, and other publicly available data.

Assuming that the data centre capacity covered by the 60 companies above represents 70–90% of the hyperscale and colocation markets, this implies that total hyperscale and colocation data centre energy consumption in the range of 220–285 TWh.

Recent estimates from industry analysts suggest hyperscale data centre capacity accounts for around 40% of global data centre capacity today, with an additional 22% from colocation data centres (Synergy Research Group, 2024b). To account for other data centres types, we assume that energy consumption from traditional (enterprise) data centres has been flat since 2018 (71 TWh in Masanet et al. (2020)) and all other data centres (e.g., non-cloud telco data centres) account for 10–20 TWh in 2023.

Based on our analysis and extrapolation of company-level data, data centres consumed **300–380 TWh in 2023.**

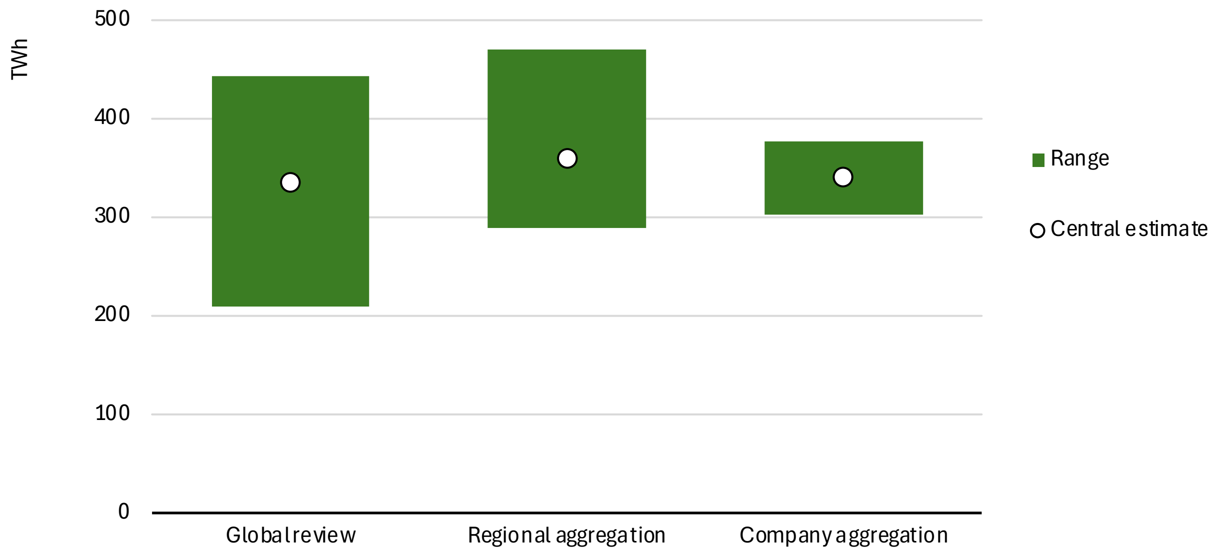
5. Discussion

5.1 Summary of results

The results of the three approaches are summarised in Figure 5.1:

- High quality global studies: 335 TWh (210–440 TWh)
- High quality regional and country-level studies: 360 TWh (290–470 TWh)
- Extrapolation of company-level data: 340 TWh (300–380 TWh).

Figure 5.1 **Results of three complementary approaches to estimate global data centre energy use in 2023**



Notes: Global review includes studies that were assessed to be '5 - High'. Central estimate indicates authors' best estimate.

Based on analysis of over 100 studies published since 2014 and data from over 60 of the largest data centre operators, we estimate that data centres globally consumed 300–380 TWh in 2023, excluding crypto.

The United States accounted for around 40% of the total, followed by China (25%) and Europe (20%).

The four largest data centre operators – Amazon, Alphabet, Microsoft, and Meta – accounted for around 90 TWh in 2023, approximately a quarter of the global total. Combined data centre energy use of these four companies has more than tripled since 2018.

5.2 Key parameters influencing results

As discussed in Section 0, we categorised the studies into several key parameters, including affiliation type (e.g. industry, government, academia), publication type (e.g. peer-reviewed, report), and modelling approach (e.g. bottom-up, temporal proxy extrapolation).

5.2.1 Modelling approach

Across all studies, we find that the modelling approach has the biggest impact on the assessed quality and results. Studies using temporal proxy extrapolation approaches were assessed to be the lowest overall quality, with the largest range in estimates.

Global estimates from studies employing temporal extrapolation had a wide range, from under 200 TWh to around 2 000 TWh in 2023. The average estimate across all scenarios in these studies was 790 TWh – over twice our estimated total for 2023 based on the best available data.

In contrast, studies using bottom-up and hybrid approaches were assessed to be of higher quality, with a much narrower range of estimates. Global bottom-up studies ranged from 210–500 TWh for 2023, with an average estimate across all scenarios of around 390 TWh. Studies employing hybrid approaches had a range of 255–525 TWh, with an average estimate of around 365 TWh.

5.2.2 Author affiliation

Affiliation type – for example, whether the researchers were from academic institutions or industry – had limited correlation with the study quality or whether the estimates were low or high.

For example, the lowest quality studies published prior to 2024 came from researchers affiliated with industry (Huawei), academia (McMaster University), and a think tank (the Shift Project). These typically had both the widest range and highest estimates of all publications (see Figure 4.1). Worst-case scenario projections for 2030 or 2040 from these studies were widely cited by the media to exaggerate the future energy and climate impact of data centres.

Meanwhile, some of the highest quality studies have come from different types of organisations, including academic and government-affiliated researchers (Lawrence Berkeley Lab, UC Santa Barbara), intergovernmental organisations (IEA), and industry (Ericsson and Telia; IDC; Semianalysis).

One notable trend over the past year is that a series of reports on data centres and AI have been published by consulting firms (BCG, Deloitte, McKinsey, S&P Global) and investment banks (Goldman Sachs, Jeffries, Morgan Stanley). With the exception of Deloitte Global (2024), these studies tend to be of lower quality (using temporal extrapolations) or lack any disclosure of methodological detail or assumptions, making quality assessments not possible.

5.2.3 Other parameters

The vast majority of estimates published since 2014 have been company or government reports, with only nine global estimates published as peer-reviewed articles. Five of these were assessed to be of low or low-medium quality, despite undergoing peer review (Andrae, 2019a, 2020; Andrae & Edler, 2015; Belkhir & Elmeligi, 2018; Liu et al., 2020). In some cases, these peer-reviewed articles were published in less reputable journals (and publishers) such as Challenges (MDPI), International Journal of Green Technology (no longer active), and Engineering and Applied Science Letters (PISRT).

Generally, studies that provided long-term projections (e.g. more than 10 years from the date of publication) were of lower quality, as they generally relied on temporal proxy extrapolations.

5.3 The limits and necessity of projections: Learning from the past

As discussed from the outset, the main motivation behind this study was the wide range of existing estimates on global data centre energy consumption. This inconsistency, which has also been addressed in the literature (Bremer et al., 2023), is emphasised in Figure 3.1 for the 2030 projections and in Figure 3.2 for current (i.e., 2022) estimates.

When it comes to the energy demand – and more generally, environmental impacts – of digital technologies, such large variation of estimates is nothing new. Over the past 25 years, there have been several such instances; two of them, however, are most noteworthy.

5.3.1 Late 1990s to early 2000s: “Dig more coal, PCs are coming”

A 1999 Forbes article titled “Dig more coal -- the PCs are coming” painted a bleak picture of the growing energy consumption of the Internet, forecasting for the US that “it’s now reasonable to project that half of the electric grid will be powering the digital-Internet economy within the next decade” (Huber & Mills, 1999). The authors of the article argued that the growth of the internet meant that further expansion of coal-fired power was necessary to maintain secure supply of electricity.

US data centre energy demand more than doubled between 2000 and 2008, approaching almost 2% of national electricity use in 2008 – but a far cry from ‘half the electric grid’. Meanwhile, coal-fired power has declined by nearly two-thirds in the US since 1999 – from nearly 1 900 TWh (51% of supply) to just 675 TWh in 2023 (16% of supply) (US EIA, 2024).

In those early days of ICT environmental impact assessment, uncertainties were particularly high, and results wide apart. As analysed by Coroamă & Hilty (2014) and then in more detail in Coroamă (2021), the two early estimates for the energy intensity of the Internet (i.e., the amount of electricity required to transmit a certain amount of data across the Internet on average) were 136 kWh/GB by Koomey et al. (2004) and 0.0064 kWh/GB by Baliga et al. (2011) – a factor of 20,000 apart.

While one order of magnitude of this gap could be explained through the efficiency gains in the seven years between the two estimates, the other three orders of magnitude stemmed from methodological differences, such as different system boundaries, deployed assumptions, and the opposing biases inherent to the two top-down and bottom-up methods used, which led to an overestimate in one case and an underestimate in the other (Coroamă, 2021). Interestingly, the study with the high-end (later proven to be substantially overstated) estimate in Koomey et al. (2004), had been written to counter the much higher assessment published by Forbes (Huber & Mills, 1999), which had generated strong public reaction.

5.3.2 Late 2010s: "Tsunami of data could consume one fifth of global electricity by 2025"

The second period of both diverging estimates and exaggerated projections started with the paper by Andrae & Edler (2015), which marks the upper end of the estimates shown in Figure 3.1.

The study's worst-case scenario projected data centre electricity consumption of nearly 8 000 TWh by 2030, equivalent to 28% of projected global electricity demand in 2030. The "expected" scenario projected data centres would use 3 000 TWh per year by 2030, which would still mean over 10% of global electricity consumption.

While formally peer reviewed – albeit by MDPI, a publisher with quality-related controversies (Brainard, 2023; Clarivate, 2025) – the study does not address obvious and crucial economic or technological feasibility questions such how the required additional power plants and electricity grids would be built or about the price increases and for, and related feasibility of, digital services in such a scenario.

The simplistic assumption deployed by the paper is that global data centre (DC) energy is a product of DC IP data traffic (PB) and its energy intensity (MWh/PB), with some of the energy demand growth mitigated by three levels of energy efficiency improvement scenarios (best, expected, and worst case). Data traffic, however, is a poor proxy for DC energy consumption, which relates more closely to the amount of computation in servers and the stored data, the former of which does not relate at all to traffic, and the latter of which only vaguely relates to traffic.

Despite these methodological, feasibility, and publishing shortcomings, the results from Andrae & Edler (2015) were included in a 2018 *Nature* "news feature" (Jones, 2018). While being a non-peer reviewed piece written by a staff journalist, the *Nature* article helped to increase the reach of the original 2015 study. As of February 2025, Andrae & Edler (2015) has been cited nearly 1 500 times, while the Jones (2018) *Nature* article has been cited over 1 000 times, as per Google scholar.

Another peer-reviewed publication, Belkhir & Elmeligi (2018), extrapolated data centre energy use to 2040 based on a 12% compound annual growth rate, implying projected data centre energy consumption of around 3 000 TWh by 2030 and nearly 10 000 TWh by 2040. The study – which focuses on the carbon emissions from the ICT sector – have also been widely quoted in news articles and has been cited over 1 100 times.

Anders Andrae, the lead author of the 2015 study, has since updated the original assumptions and estimates – reflecting the new insights – in subsequent publications in 2019 and 2020 (Andrae, 2019b, 2020). For example, 2030 'expected' projection in the most recent 2020 article is 974 TWh – three times lower than the 'expected' projection (2 967 TWh) in the original 2015 study. At the same time, however, the old vastly overstated numbers not only gained momentum through the *Nature* news feature mentioned above, but also through a study published in early 2019 by the Shift Project, a French think tank, adapting the original 2015 model.

Building on the Andrae & Edler (2015) model and adding own assumptions and calculations on the network energy consumption, this study estimated that video streaming emits 3.2 kg CO_2 per hour (The Shift Project, 2019a). This estimate was picked up by several major newspapers and media outlets on both sides of the Atlantic, including Le Monde, The Guardian, NZZ, and Wired. Several other media outlets subsequently reported that "the emissions generated by watching 30 minutes of Netflix [1.6 kg of CO2] is the same as driving almost 4 miles" – among them the New York Post, CBC, Yahoo, DW, Gizmodo, Phys.org, and BigThink (Kamiya, 2020a, 2020b).

As detailed in a subsequent fact check published by Carbon Brief and the International Energy Agency, the Shift Project analysis had not only used the outdated and overstated numbers from Andrae & Edler (2015) but introduced own questionable assumptions and errors, such as mistakenly using bytes instead of bits and thus introducing an error factor of eight (Kamiya, 2020a, 2020b). Overall, the study overstated the energy and climate impact of video streaming by two orders of magnitude.

5.3.3 Current AI-driven energy surge: Déjà vu or is it for real?

Both examples above show periods of vast overestimates of the energy or GHG impact of ICT, in the context of high uncertainties and widely varying estimates. In both cases, history has shown that the more conservative, lower estimates were closer to the truth. Both examples also show how easily the alarmistic estimates or projections were spread in the past once picked up by mainstream media, even though they relied on thin scientific evidence. Past experiences also show how difficult it is to correct the alarmistic numbers once they entered public consciousness – a phenomenon referred to as Brandolini's law (Williamson, 2016).

As shown throughout this study, in the past, the higher-quality estimates typically yielded more conservative values, and have later been proven right. There is, however, widespread concern that the energy consumption induced by AI might indeed lead to a quickly increasing data centre energy use. The question thus arises whether this is now yet another moment of alarmistic overstatements or whether this time the concerns are legitimate and there is a possibility, perhaps even a large likelihood, that AI might indeed induce a sharp growth in data centre energy demand.

Past overstatements notwithstanding, it is clear that data centre energy consumption is currently on the rise largely driven by surging demand for generative AI. While server and data centre infrastructure efficiency gains coupled with the shift to cloud and hyperscale data centres largely compensated the growing demand in digital services between 2010 and 2018 (Masanet et al., 2020), this is no longer true today. The estimated total data centre electricity use of 60 of the largest operators has doubled between 2018 and 2023, while the combined data centre electricity use for the four largest operators has more than tripled (Section 4.4).

Additionally, sources that we consider highly credible such as Shehabi et al. (2024) project a further, more rapid growth, with roughly a doubling within the next four to five years in the US. Given the considerable corporate and government interest in rapid AI development in other regions including Europe and Asia, it is highly plausible to foresee continued growth in data centre energy use globally.

Global data centre energy use rose by around 6% between 2010 and 2018 (Masanet et al., 2020), equivalent to an average annual growth rate of 0.7% per year. However, since 2018, global data centre energy use has grown by around 50–80%, equivalent to an average annual growth rate of 8–13% per year. If these trends continue, this implies a range of global data centre energy consumption of 600–800 TWh in 2030, equivalent to 1.8–2.4% of global projected electricity demand in 2030. A higher growth rate of 20% driven by AI could result in energy consumption in the range of 1 100–1 400 TWh, equivalent to 3–4% of global projected electricity demand in 2030.

Based on the review of existing AI energy studies (Section 3.3) and an economic plausibility assessment (Section 3.3.3), we project AI-related data centre energy use to increase from around 30–50 TWh in 2023 to 200–400 TWh by 2030. In other words, we expect AI-related energy use in data centres to increase from 10–15% of overall data centre energy use in 2023 to 35–50% in 2030.

While the growth of data centres and AI are expected to be an important driver of electricity demand growth, electric vehicles, air conditioners, and electricity-intensive manufacturing are expected to be larger drivers of electricity demand growth globally (IEA, 2024b; Spencer & Singh, 2024).

It is important to acknowledge that the current and future energy demand impacts of data centres are unevenly distributed around the world. Data centres already account for over one-fifth of overall electricity demand in Ireland and Virginia. While the overall growth at the global level are smaller than other demand drivers discussed above, the highly concentrated nature and very high power density of data centres creates significant challenges at the local level, including grid connection and capacity constraints, water consumption, and community opposition.

6. Conclusions and recommendations

6.1 Summary of key conclusions

The main objective of this study was to identify and critically review data centre energy estimates to understand the current (2023) global energy use of data centres. Over 50 publications with global estimates were identified and critically reviewed, including 35 with estimates, projections, or extrapolated values for the year 2023.

The review process evaluated each study's methods and the data sources, with quality assessed on a six-point scale: low, low-medium, medium, medium-high, high, and very high. Publications that did not provide sufficient detail regarding their methodologies were categorised as 'not assessed' (N/A).

Studies assessed as 'low' (seven publications) – all using temporal extrapolation approaches – had the widest range of estimates and projections for the year 2023, ranging from 480 TWh to 2 000 TWh across 17 scenarios and cases. Studies of higher assessed quality (low-medium and higher, 22 publications) had a much lower and narrower range of estimates (190–560 TWh) across 43 scenarios and cases. The eight high-quality studies (covering 12 estimates) yielded results in the range of 210–440 TWh in 2023, with an average base case estimate of 335 TWh.

To corroborate these results, we pursued two further assessment methods: the aggregation of high-quality regional and country-level studies and the aggregation of company-level data.

The global aggregation based on regional and country-level estimates followed the same approach as the global review. Partially overlapping with the global studies, 23 publications related to the US, 44 on Europe, 11 on China, and 12 on the rest of the world were reviewed. Some of the regional estimates – unlike their global counterparts – were assessed to be of a 'very high' quality. The aggregation of best available regional estimates yields a range of 290–470 TWh in 2023, with a central (best guess) estimate of 360 TWh.

For the aggregation of company-level data, reported energy consumption data from sustainability reports and other public disclosures of 60 of the largest data centre operators were collected and analysed. Extrapolating these figures to the entire market and adding a third-party estimate for enterprise data centres resulted in a range of 300–380 TWh in 2023.

The range of values resulting from these three largely independent approaches corroborate well. Combining the results of these three approaches, we estimate that the operational **global data centre energy use in 2023 was 300–380 TWh.**

This study also proposes new, more precise terminologies to classify modelling approaches. The literature typically refers to studies that employ extrapolations into the future (based on high-level proxies), as 'extrapolation'. To avoid confusion with other extrapolation methods such as scope extrapolation (to cover a region or market), we propose a more precise term of 'temporal proxy extrapolation'. In addition, we note that what are typically referred to as 'top-down' methods are actually the aggregation of bottom-up assessments and should be referred to as 'aggregated totals'. True top-down assessments in this field (e.g., based on quantitative system dynamics) exist, but are few and far between.

Given its importance in driving data centre energy growth, this review includes a deep dive into existing AI energy assessments, covering both current estimates and projections. While all sources agree that currently AI is responsible for a relatively modest total amount of just a few dozen TWh globally per year, projections for 2028 to 2030 diverge considerably. By the end of the decade, some studies project AI energy consumption to grow to 200–400 TWh, while others project a much larger growth to 600–900 TWh. Due to economic and further constraints, we believe the former to be more likely.

6.2 Recommendations

To conclude the report, we offer a series of recommendations to key stakeholders – data centre energy modellers, data centre companies, policymakers, journalists, and civil society – on how they can contribute to better data, models, and estimates to inform decision making.

6.2.1 Improving models and estimates

Drawing on key lessons and guidance from Bremer et al. (2023), Koomey & Masanet (2021), Masanet et al. (2024), Mytton & Ashtine (2022) we recommend the following areas of action to improve data centre energy models and estimates.

Improve data collection, quality, and transparency

- Companies and governments should improve data accessibility and transparency through systematically collecting and publicly reporting timely, high-quality data on data centre energy use at company and country levels. This can be encouraged by investors as well as government policies and regulations such as the EU Energy Efficiency Directive[4].
- Data centre energy modellers should collect data instead of making assumptions whenever possible. Modellers are encouraged to validate and improve their models by anchoring data and assumptions with real world data and measurements.
- Data centre energy modellers should report their results precisely and transparently.

Increase methodological rigour and transparency

- Data centre energy modellers should clearly define system boundaries (e.g. what type of data centres are included or excluded, whether the results include crypto). Methodologies and data sources should be clearly and comprehensively described and cited to enable replication.

[4] The revised EU Energy Efficiency Directive (EU/2023/1791) introduces obligations for data centres with total IT power over 500 kW to publicly report their energy performance data annually.

- Data centre energy modellers should use bottom-up modelling approaches based on granular data, combined with other modelling approaches and perspectives to triangulate and validate results. For global estimates, top-down models such as quantitative system dynamics or input-output analyses can be helpful for validation.
- Modellers should critically assess any input data sources and assumptions. Old data and assumptions should not be used to estimate current or future impacts due to the fast-moving nature of digital technologies.
- Given the significant future uncertainty of digital technologies and their energy use characteristics, modellers should develop “what if” scenarios that reflect a range of possible outcomes based on different trajectories for bottom-up drivers.
- Long-term projections (beyond five years) should be avoided. Modellers should acknowledge and use caution when drawing conclusions from extrapolations beyond a few years.
- Economic, technological and societal constraints such as foreseen costs, power grid availability and societal acceptance can be helpful validation approaches.
- Journal editors should ensure thorough and robust review processes and include ICT energy experts as reviewers.

6.2.2 Guidelines for interpreting and critically assessing studies

Journalists, policymakers, and other non-experts can ask the following questions when assessing the quality of studies. If the answer is “no” or “I don’t know” to more than two of the following, the study is likely to be of lower quality.

- Does the study rely primarily on measured data (e.g. company data, national estimates or data from governments) and/or bottom-up modelling approaches?
- Does the study clearly state the scope of analysis, and what is included or excluded from the analysis?
- Do the research authors have demonstrated expertise in data centre energy modelling?
- If the study includes projections more than five years from today, does it include more than one scenario? Do the authors use bottom-up drivers to project future demand instead of extrapolating compound annual growth rates (CAGR)?

6.2.3 Summary of recommendations

Energy modellers, data centre companies, governments, journalists, and civil society all have important roles to play in improving the quality of assessments. Table 6.1 summarises our key recommendations for each stakeholder group.

Table 6.1 Recommendations for key stakeholders

Stakeholder	Best practice (Do)	Poor practice (Don't)
Data centre energy modellers	✓ Use bottom-up modelling approaches and granular data, combined with other modelling approaches and perspectives to triangulate results ✓ Explain methodology and cite data sources comprehensively and transparently ✓ Report results precisely and transparently, ideally in a table format ✓ Develop "what if?" scenarios and sensitivity analyses to understand and explore uncertainties ✓ Analyse the whole system ✓ Advocate for policies that promote data collection and transparency regarding the energy use of data centres to improve research quality ✓ Consider economic, technological, societal, and other practical constraints	× Combine retrospective intensity parameters (e.g. energy intensity of data centre IP traffic) with projected future service demand to project future energy demand × Average key parameters × Extrapolate results more than 5 years from baseline data using 'expert judgment' compound annual growth rates × Cite sources of key results or analysis as "Company X analysis or model"
Data centre companies	✓ Increase reporting frequency, timeliness, and detail (at minimum, total energy use of data centres; ideally at the data centre level) ✓ Disclose energy data transparently and consistently, e.g. in a table format with clear definitions ✓ Support policies that promote data collection and transparency to support policy and strategic discussions based on sound research	× Fail to disclose any energy or environmental data × Hide or obscure key energy data (e.g. company-wide energy use)
Policymakers and regulators	✓ Implement policies and regulations that require data centre operators to disclose key energy use information ✓ Collect, validate, and publish national and regional data regarding data centre energy consumption ✓ Base policy decisions on multiple credible sources	× Base policymaking on sources developed by those with limited domain expertise or conflicts of interest
Journalists	✓ Avoid cherry picking the most extreme scenarios and projections ✓ Provide context for readers, including key uncertainties and distinctions between local and global impacts ✓ Critically assess the quality of studies, and speak to multiple experts to understand the quality of new research	× Cherry-pick the most extreme scenario results to exaggerate or downplay the energy and environmental impact of data centres
Civil society	✓ Advocate for policies that promote data collection and transparency regarding the energy use of data centres	× Develop or amplify poor quality analysis or extreme results to support positions

Sources: Developed by authors drawing on Koomey & Masanet (2021) and Masanet et al. (2024).

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