

# ENERGY - EFFICIENT DATA CENTRES

## A HIGH-LEVEL OVERVIEW

*eu-LISA Research and Technology Monitoring Report 2026*



## ***Acknowledgements***

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<sup>1</sup> [Sopra Steria Group](#) is an European consulting company, focusing on sustainable digital transformation.

<sup>2</sup> [RISE Research institutes of Sweden](#) is an independent government research institute, with a mission to support the transition towards a sustainable society by strengthening public sector competitiveness through innovation.

# TABLE OF CONTENTS

---

EXECUTIVE SUMMARY .....	6
INTRODUCTION .....	8
<b>1. KEY ASPECTS OF ENERGY-EFFICIENT DATA CENTRES .....</b>	<b>11</b>
1.1. FUNDAMENTALS .....	12
1.2. DATA CENTRE ENERGY PERFORMANCE .....	18
<b>2. REGULATORY FRAMEWORKS FOR ENERGY EFFICIENCY .....</b>	<b>29</b>
2.1. EUROPEAN UNION .....	30
2.2. INTERNATIONAL OUTLOOK .....	39
<b>3. STATE OF PRACTICE .....</b>	<b>45</b>
3.1. SURVEY ON DATA CENTRE ENERGY EFFICIENCY .....	46
3.2. INSIGHTS FROM EU-FUNDED PROJECTS .....	51
3.3. INSIGHTS FROM HYPERSCALERS .....	53
<b>4. INNOVATIVE TECHNOLOGIES TO IMPROVE ENERGY EFFICIENCY .....</b>	<b>55</b>
4.1. EMERGING INFRASTRUCTURE TECHNOLOGIES FOR ENERGY-EFFICIENT DATA CENTRES .....	56
4.2. AI SOLUTIONS DRIVING ENERGY OPTIMISATION IN DATA CENTRES .....	62
<b>5. GENERAL CONSIDERATIONS TO IMPROVE DATA CENTRE ENERGY PERFORMANCE .....</b>	<b>67</b>
5.1. OPTIMISING DATA CENTRE OPERATIONS .....	68
5.2. ADDING RENEWABLE ENERGY TO THE POWER SUPPLY MIX .....	71
5.3. MANAGING OWN FACILITY VERSUS USING SERVICE PROVIDERS .....	72
<b>CONCLUSION .....</b>	<b>Error! Bookmark not defined.</b>
<b>ANNEXES .....</b>	<b>Error! Bookmark not defined.</b>
Annex I. SURVEY QUESTIONNAIRE .....	79
Annex II. EU-FUNDED PROJECTS FROM 2015 to 2027 .....	82

# TABLES AND FIGURES

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## List of Tables

Table 1. HDD/CDD 18C reference temperature in Toulouse and Strasbourg, France.....	16
Table 2. Tier classification for data centre site infrastructure.....	17
Table 3. ISO/IEC 30134:2016 series of standard KPIs for tracking data centre efficiency.....	19
Table 4. Data centre energy efficiency categories based on PUE reference values.....	20
Table 5. Advantages and limitations of using PUE.....	22
Table 6. Data centre energy efficiency categories based on REF reference values .....	24
Table 7. Data centre energy efficiency categories based on ERF reference values .....	25
Table 8. Data centre energy efficiency categories based on WUE reference values .....	26
Table 9. EU regulatory framework for improving energy efficiency in data centres .....	31
Table 10. European best practice frameworks for improving energy efficiency in data centres ...	36
Table 11. International best practice frameworks for improving energy efficiency in data centres	39
Table 12. PUE-based data centre energy efficiency classification in China .....	43
Table 13. Data centre energy efficiency maturity levels .....	47
Table 14. Maturity levels of surveyed organisations, by role.....	49
Table 15. Overview of EU-funded projects 2015-2027 under Horizon 2020 / Horizon Europe ....	51
Table 16. Data centre energy performance improvements reported by hyperscalers.....	53
Table 17. Advantages and disadvantages of power distribution types in the 20 to 50kW range..	61
Table 18. AI-supported initiatives by hyperscalers .....	64
Table 19. SWOT analysis: data centre ownership versus hosted infrastructure services .....	72
Table 20. Sources for SWOT analysis presented in Table 19 on page 75 .....	75

## List of Figures

Figure 1. Report preparation process integrating research and state of practice.....	9
Figure 2. Data centre components.....	13
Figure 3. Breakdown of power usage within a data centre .....	14
Figure 4 Share of electricity consumption by data centre and equipment type, 2024 .....	15
Figure 5. Global average annual PUE of data centres, 2007-2025 .....	21
Figure 6. EU reporting scheme: PUE values of European data centres, 2024 .....	21
Figure 7. EU dashboard on data centre energy efficiency (screenshot 20 April 2026) .....	32
Figure 8. Climate Neutral Data Centre Pact pledges to become climate neutral by 2030.....	38
Figure 9. Data Center Energy Efficiency Toolkit .....	41
Figure 10. Standard capability maturity level .....	46
Figure 11. Spider chart of surveyed maturity levels.....	49
Figure 12. Nvidia 800V HVDC architecture for minimised energy conversion losses .....	60

## ACRONYMS AND ABBREVIATIONS

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<b>AI</b>	artificial intelligence
<b>CoC</b>	Code of Conduct
<b>CNDCP</b>	Climate Neutral Data Centre Pact
<b>CPU</b>	central processing unit
<b>CSRD</b>	Corporate Sustainability Reporting Directive
<b>DG ENER</b>	Directorate-General for Energy under the European Commission
<b>EED</b>	Energy Efficiency Directive
<b>ERF</b>	energy reuse factor
<b>ESPR</b>	Ecodesign of Sustainable Products Regulation
<b>ESRS</b>	European Sustainability Reporting Standards
<b>eu-LISA</b>	EU Agency for the Operational Management of Large-Scale IT Systems in the Area of Freedom, Security and Justice
<b>EUDCA</b>	European Data Centre Association
<b>EUDCEAR</b>	EU Data Centre Energy Efficiency Assessment and Reporting Scheme
<b>GHG</b>	greenhouse gases
<b>GoO</b>	guarantee of origin
<b>GPP</b>	Green Public Procurement
<b>HVDC</b>	high-voltage direct current
<b>IEA</b>	International Energy Agency
<b>IT</b>	information technology
<b>ICT</b>	information and communication technology
<b>ISO</b>	International Organization for Standardization
<b>JRC</b>	Joint Research Centre under the European Commission
<b>KPI</b>	key performance indicator
<b>LCA</b>	life cycle assessment
<b>MEPS</b>	minimum energy performance standards
<b>MPS</b>	minimum performance standards
<b>MSP</b>	managed service providers
<b>PPA</b>	power purchase agreement
<b>PSU</b>	power supply unit
<b>PUE</b>	power usage effectiveness
<b>REC</b>	renewable energy certificate
<b>ROI</b>	return on investment
<b>REF</b>	renewable energy factor
<b>SBTi</b>	Science Based Targets initiative
<b>UNEP</b>	United Nations Environment Programme
<b>UPS</b>	uninterruptible power supply
<b>WUE</b>	water usage effectiveness

## EXECUTIVE SUMMARY

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Data centres are becoming a critical component of the EU's energy system, already accounting for around 3% of electricity demand, with expected growth due to the increasing use of cloud computing and artificial intelligence. Considering the rising share of data centres in overall energy consumption, this report provides a high-level assessment of the current state of energy efficiency in data centres, combining insights from policy frameworks, research, technological developments, best practices, and outcomes from a small-scale survey of EU organisations managing their own data centres.

The report can be summarised around five main takeaways:

- **Energy efficiency improvements require a holistic, system-level approach.** Isolated optimisations, such as improving server efficiency or cooling systems alone, are insufficient. Instead, high-performing data centres should integrate efficiency measures across the entire infrastructure, from IT equipment and power supply to cooling and backup systems, supported by continuous monitoring, telemetry, and feedback-driven optimisation loops, enabling dynamic efficiency improvements during operation.
- **Changes in how sustainability is measured.** Although power usage effectiveness (**PUE**) remains the key indicator for energy efficiency, it cannot be equated with the general sustainability level of data centres. There is a clear transition towards multi-metric sustainability assessment frameworks, incorporating multiple indicators alongside energy efficiency to evaluate data centre sustainability, such as the renewable energy factor (**REF**), energy reuse factor (**ERF**), and water usage effectiveness (**WUE**). This reflects a broader understanding that sustainability must also include energy sourcing, water consumption, and waste heat recovery, in addition to facility-level energy efficiency.
- **Progress across the data centre sector is uneven.** There is a clear variation of maturity levels across data centre operators. Leading organisations, such as hyperscalers, are already testing and implementing advanced practices such as modular design, AI-driven optimisation, liquid cooling, waste heat reuse and integration with renewable energy systems. However, many organisations managing their own data centres still lag behind, particularly in areas such as monitoring water usage, and lifecycle-based sustainability management.
- **Increasing role of regulatory instruments for improving sustainability.** EU-level policy and strategic instruments, such as the European Green Deal and the Energy Efficiency Directive, are introducing mandatory reporting requirements which are expected to enable better benchmarking, increase transparency, and introduce performance rating schemes and minimum energy efficiency thresholds. In short, the new regulatory framework is accelerating the transition from voluntary best practices to mandatory reporting of sustainability performance.
- **Technology innovation plays a critical role in improving energy efficiency.** Considerable effort is being put into research and innovation to improve the energy efficiency of data centres in the short- to mid-term future. These technological developments include innovative cooling techniques, energy storage (e.g., innovations in batteries, hydrogen storage and fuel cells), and current distribution standards based on high-voltage direct current (HVDC). These innovations are complemented by AI-based solutions that enable real-time monitoring and optimisation of energy consumption. While these advancements are expected to deliver significant gains in energy efficiency in the coming years, it is important to recognise that technology innovation alone is not sufficient. Technologies can only maximise their potential when integrated into coherent operational strategies and governance frameworks, rather than deployed as isolated solutions.

Achieving meaningful improvements in energy efficiency requires a **strategic and cultural shift from component-level optimisation to lifecycle-oriented and data-driven management models**. Therefore, sustainability must move beyond incremental 'quick wins' and become a core organisational principle, embedded in decision-making across the entire life cycle of data centre design, procurement, operation, and decommissioning, supported by robust and transparent frameworks based on clear sustainability metrics and KPIs. Organisations that adopt this integrated approach will be better positioned to support both EU climate objectives and the growing demand for resilient digital infrastructure.

# INTRODUCTION

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The accelerating digital transformation of society has placed data centres at the core of our daily lives, making their **energy usage**, **environmental impact**, and **operational resilience** a central concern. In the context of EU climate neutrality ambitions, data centres are under increasing scrutiny to demonstrate not only operational excellence, but also measurable improvements in environmental sustainability. To address these concerns, this report provides a comprehensive exploration of both the **state of the art** and **state of practice** in this area. First, it provides an overview of sustainable data centre operations, drawing on a survey of leading European public and private organisations, coupled with lessons from over 20 EU-funded innovation projects. Second, it seeks to offer practical, evidence-based recommendations to guide the energy efficient operation of data centres in line with evolving policy requirements and technology developments.

## *Data centres supporting the operation of EU's large-scale IT systems*

Energy efficiency is a critical consideration for eu-LISA, who operates the EU's large-scale information systems in the domain of justice and home affairs (JHA), supporting key EU policies in the areas of border management, migration, asylum, and internal security. The continuous and secure operation of these IT systems relies on **highly available data centre infrastructure**. Since the processing, storage, and exchange of large data volumes requires substantial computing resources, the data centres operated or used by eu-LISA consume significant amounts of electricity. Therefore, improving the energy efficiency of these facilities is essential not only for the purposes of reducing operational costs but also to ensure the long-term sustainability and resilience of the digital infrastructure managed by eu-LISA.

Moreover, energy efficiency efforts are also with the broader environmental and climate neutrality objectives of the **European Green Deal**, and the reporting requirements stemming from the **Energy Efficiency Directive** (EED). As a EU agency, eu-LISA contributes to these objectives by adopting resource efficient operational practices and by ensuring that its IT infrastructure is managed in an **environmentally sustainable** manner. This includes monitoring energy performance, improving the efficiency of data centre equipment and cooling systems, increasing the share of renewable energy in its power supply and deploying innovative technologies. In this context, understanding the current performance of data centres and identifying potential improvements becomes a **strategic priority**.

Therefore, this report on the energy efficiency of data centres serves multiple purposes for eu-LISA and its stakeholders. On the one hand, the report provides a baseline for the Agency to assess the energy performance of its IT infrastructure, as well as identify **best practices and technological solutions** for improving energy efficiency, with a view to reducing energy consumption while also maintaining the high availability and reliability required for critical EU information systems. On the other hand, the report provides a structured knowledge base to support future infrastructure planning and procurement decisions, ensuring that sustainability considerations are incorporated into the design and operation of eu-LISA's data centre operations. Ultimately, by analysing energy efficiency in its data centres, eu-LISA can contribute to the EU's broader sustainability goals while continuing to strengthen its operational efficiency and resilience of the digital systems under its management.

## *Report structure*

The report is structured into five chapters that outline the performance aspects, regulatory frameworks, and technological context shaping the energy efficiency of data centres.

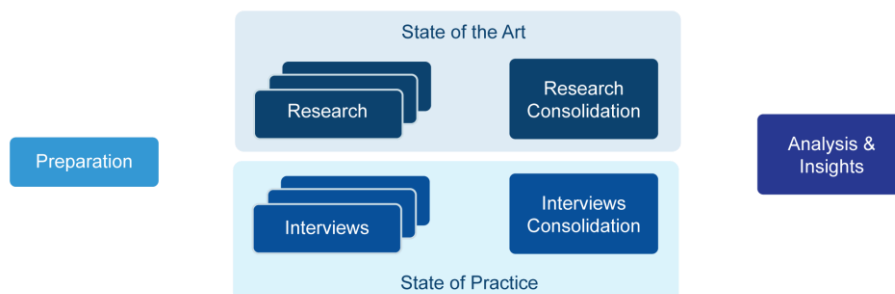
The first chapter outlines the fundamental elements influencing data centre energy consumption, together with **key performance metrics** for measuring energy efficiency, focusing in particular on power usage effectiveness (PUE). To provide a more comprehensive approach, the report also includes several other complementary indicators related to renewable energy use, waste heat recovery and water usage. These metrics are considered essential for benchmarking facilities, monitoring performance and identifying inefficiencies to drive improvements over the long term

The second chapter provides an overview of the **regulatory landscape** in the EU and also at the global level, listing relevant EU legislation together with best practice frameworks that provide guidance for improving energy efficiency of digital infrastructure. These frameworks foster the adoption of more efficient technologies and operational practices, while also increasing transparency by mandating reporting on energy performance. The report highlights how such policies address the growing energy demand of digital services while supporting the EU's broader climate neutrality and sustainability objectives. The chapter concludes with brief overviews of developments in the United States, Japan and China.

The third chapter provides an overview of the **state of practice** in this area, drawing on a small-scale survey of European organisations, and an overview of best practices from EU-funded innovation projects, and hyperscalers. As depicted in Figure 1 below, the survey conducted by Sopra Steria for the purposes of this report unfolded along two paths:

- state of the art definition and innovative practices in energy efficiency, drawing on research conducted by domain experts,
- **small-scale survey of selected organisations** to gather insights from real world energy management practices.

**Figure 1. Report preparation process integrating research and state of practice**



In addition to the survey, state of practice is illustrated with select **examples from EU-funded projects**, highlighting the role of innovation in shaping the energy efficiency solutions for future data centres. The report highlights emerging trends in the areas of on-site generation of low-carbon energy, waste heat valorisation and energy efficient operation of digital infrastructure. The chapter concludes with a brief overview of innovations introduced by hyperscalers.

The fourth chapter explores **innovative technologies** for improving data centre energy efficiency, from emerging infrastructure technologies to AI-based solutions for energy optimisation, in particular predictive maintenance, and smarter workload management that can reduce energy consumption while maintaining high levels of reliability and performance. Together, these technological developments illustrate how innovation can play a key role in improving data centre energy efficiency as demand for digital services continues to grow.

The report concludes with a chapter pooling general **insights and recommendations** from research and best practices of data centre operators, ranging from infrastructure optimisation and integration of renewable energy sources to considerations related to managing own data centre facility versus using cloud technologies.

# KEY ASPECTS OF ENERGY-EFFICIENT DATA CENTRES



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# 1. KEY ASPECTS OF ENERGY-EFFICIENT DATA CENTRES

The first part of this chapter outlines the most important aspects of data centres, focusing on key components and the conditions influencing their energy consumption and performance.

In the context of data centres, energy efficiency relates primarily to **how energy is sourced, used, and reused** for the data centre facility and IT equipment. To that end, organisations use internationally recognised metrics to **measure, monitor, track** and **report** on their energy performance. This report focuses on energy performance metrics that are mandated by the EU regulatory framework to drive continuous improvement to reach net-zero emissions by 2050:

- power usage effectiveness (**PUE**),
- renewable energy factor (**REF**),
- energy reuse factor (**ERF**),
- water usage effectiveness (**WUE**).

This approach reflects the EU's objective of addressing the environmental footprint of digital infrastructure in a more comprehensive manner, including cooling water consumption, integration with renewable energy systems, and opportunities for waste heat reuse in district heating networks.

## 1.1. FUNDAMENTALS

1.1.1. Definition, categorisation and components

1.1.2. Data centre energy consumption

1.1.3. Site conditions influencing energy efficiency

## 1.2. DATA CENTRE ENERGY PERFORMANCE

1.2.1. Power usage effectiveness (PUE)

1.2.2. Renewable energy factor (REF)

1.2.3. Energy reuse factor (ERF)

1.2.4. Water usage effectiveness (WUE)

## 1.1. FUNDAMENTALS

Data centres have become the backbone of our modern digitalised societies, enabling the secure transfer and storage of data and information that drives our everyday lives, from online banking and streaming services to business operations and cloud computing.

### 1.1.1. Definition, categorisation and components

The International Organization for Standardization (ISO) defines ‘data centres’ as follows:

*a structure, or group of structures, dedicated to the **centralised accommodation, interconnection and operation** of information technology and network telecommunications equipment providing data **storage, processing and transport** services together with all the facilities and infrastructures for power distribution and environmental control together with the necessary levels of resilience and security required to provide the desired service availability.*<sup>3</sup>

At the EU level, the definition for data centres is very much in line with the ISO standardised terminology, defined as ‘a structure or a group of structures used to **house, connect and operate** computer systems/servers and associated equipment for data **storage, processing and/or distribution**, as well as related activities’.<sup>4</sup>

#### 1.1.1.1. Categorisation

The EU’s common rating scheme categorises data centres by **type and size**.<sup>5</sup> Based on **type**, data centres are grouped under the following categories:

- **enterprise data centre**: on-premises solution operated by an enterprise for its own use, hosting own IT infrastructure and data to deliver and manage its IT needs;
- **colocation data centre**: operators who lease only space (incl. power and cooling capacity) to customers who install and manage their own IT equipment and services;
- **co-hosting data centre / managed service providers (MSP)**: operators who provide both the physical space and computing equipment (i.e., networks, servers, storage equipment) as a service to customers who manage their own services and applications.<sup>6</sup>

Based on **size**, data centres range on a scale from ‘very small’, starting from 100 kW, to ‘very large’, exceeding 10 MW.<sup>7</sup> Among the latter category, it is worth highlighting the massive data centre facilities operated by major technology companies usually referred to as **hyperscalers** (e.g. Amazon Web Services (AWS), Google Cloud Platform, Microsoft Azure, Meta). Hyperscalers can be broadly described as large-scale cloud service providers that operate scalable, highly efficient and highly automated data centres to support cloud services (e.g., computing and storage), web hosting and, increasingly, AI services, allowing them to deliver services to millions of users around the world.<sup>8</sup>

<sup>3</sup> [ISO/IEC 30134-1:2016](#), p 3.1 Terms and definitions, 3.1.4. *Note 1*: A structure can consist of multiple buildings and/or spaces with specific functions to support the primary function. 2: The boundaries of the structure or space considered the data centre, which includes the ICT equipment and supporting environmental controls, can be defined within a larger structure or building.

<sup>4</sup> At the EU level, ‘data centre’ definition is provided in Annex A, point 2.6.3.1.16, of [Regulation \(EC\) No 1099/2008](#) on energy statistics; via [Energy Efficiency Directive Article 2 Definitions \(49\)](#).

<sup>5</sup> [Commission Delegated Regulation \(EU\) 2024/1364](#) on the establishment of **EU rating scheme for data centres**.

<sup>6</sup> [Article 2](#) of Commission Delegated Regulation (EU) 2024/1364, and elaborated in further detail in the [2025 Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency](#), p. 8.

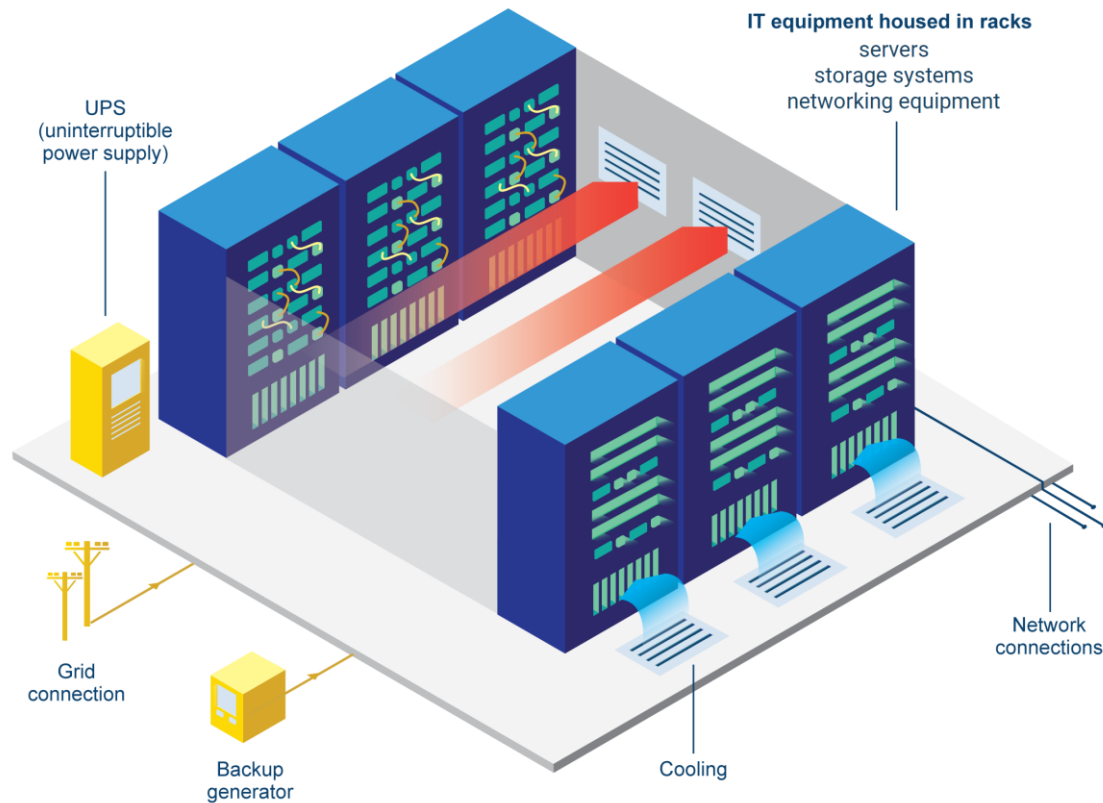
<sup>7</sup> Commission Delegated Regulation (EU) 2024/1364, [Annex IV](#).

<sup>8</sup> [World Energy Outlook Special Report – Energy and AI](#), International Energy Agency (IEA), 2025, p. 52.

### 1.1.1.2. Data centre components

Based on the ISO and EU definitions, data centres are facilities used to house **servers**, **storage systems**, **networking equipment** and associated components that are typically installed in racks and organised into rows, as depicted in Figure 2 below.

Figure 2. Data centre components<sup>9</sup>



In general, the IT and non-IT equipment needed to run the data centre, comprises the following:<sup>10</sup>

- **servers** are computers that process and store data. They can be equipped with central processing units (CPUs) and specialised accelerators, e.g., graphics processing units (GPUs). On average, they **account for around 60% of electricity demand** in modern data centres;
- **storage systems** are devices used for centralised data storage and backup; on average, they account for **around 5%** of electricity consumption;
- **networking equipment** includes switches to connect devices, routers to direct traffic and load balancers to optimise performance, accounting for **up to 5%** of electricity demand;
- **cooling and environmental controls** consist of equipment that regulates temperature and humidity to keep IT equipment operating in optimal conditions, i.e. chillers, pumps, ventilation, computer room air handling (CRAH) units, etc.<sup>11</sup> The share of cooling systems in total data centre consumption varies from about **7%** for efficient hyperscale data centres to **over 30%** for less-efficient enterprise data centres;
- **uninterruptible power supply (UPS) batteries** and **backup power generators** keep the data centre powered during outages. These are rarely used but are necessary to ensure the extremely high levels of reliability that data centres must meet;
- other infrastructure includes lighting and office equipment for onsite staff, etc.

<sup>9</sup> Adapted from *World Energy Outlook Special Report – Energy and AI*, International Energy Agency (IEA), 2025, p. 52.

<sup>10</sup> *World Energy Outlook Special Report – Energy and AI*, International Energy Agency (IEA), 2025, pp. 52-53.

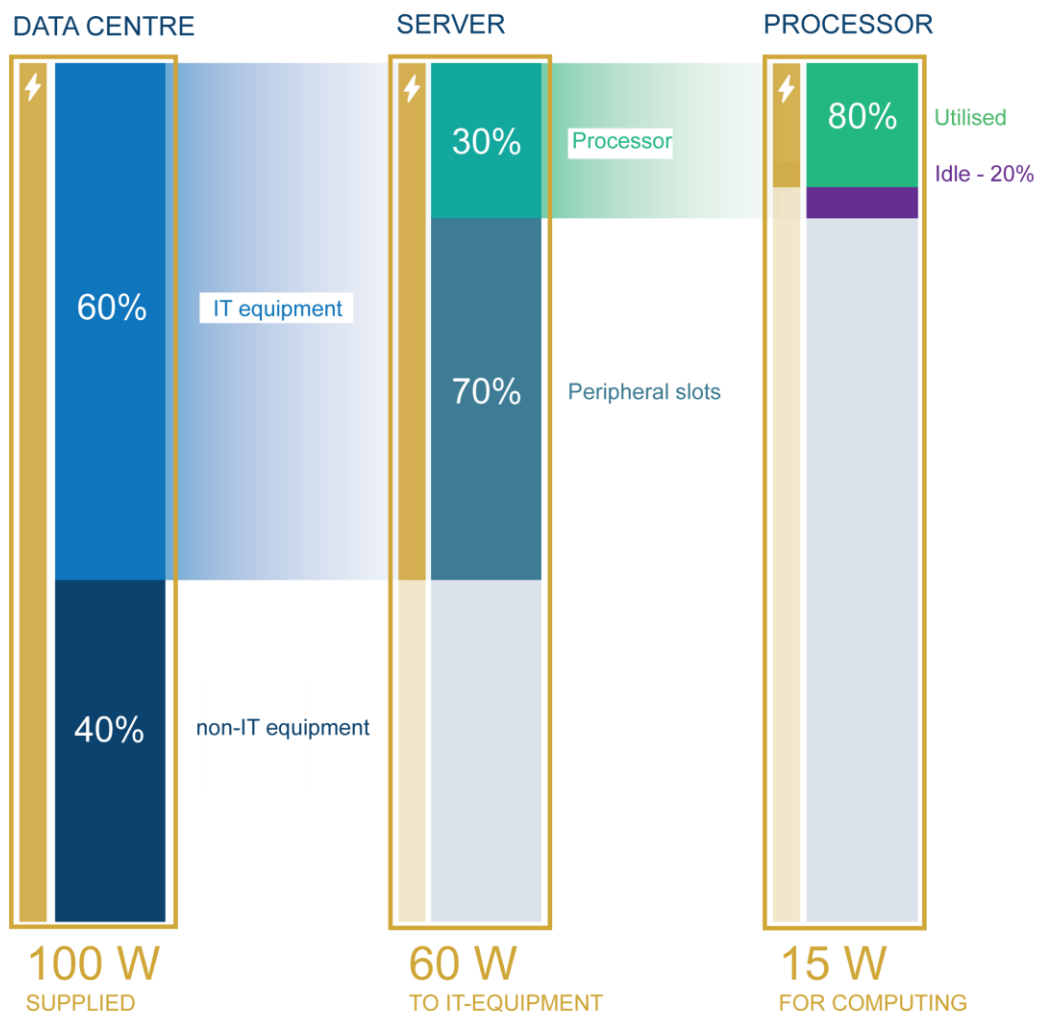
<sup>11</sup> In the context of data centres, '**cooling**' refers to heat reduction techniques such as **air cooling** (fans or air conditioning), **liquid cooling** (water or refrigerants) and **free cooling** (outside air), whereas '**chilling**' refers to a specific type of cooling where temperature is reduced to the range above freezing, usually below 8°C.

### 1.1.2. Data centre energy consumption

Analyses of data centre electricity usage have demonstrated that a significant share of energy is actually consumed before it is used by the processor for actual computing. Figure 3 illustrates how electrical energy is distributed and consumed by different components from the point of supply down to actual computation, based on the latest reports on the topic:<sup>12</sup>

- approximately **60% electricity is consumed by IT equipment**, i.e. servers, storage, network, leaving around 40% for general facility processes such as cooling, ventilation, lighting;
- we can assume that around **70%** of electricity going to IT equipment is consumed by **peripheral components**, i.e., slots, racks, motherboards, memory, storage, and fans;
- that leaves **approximately 30% for the processor**, and even if the central processor is used at a relatively high rate of 80%, only around **15%** of the total electricity supplied to the data centre is eventually consumed for **actual computing**;
- as a result, in this particular example, **around 85%** of the power supplied to and consumed by the data centre is **used before computation**.

Figure 3. Breakdown of power usage within a data centre



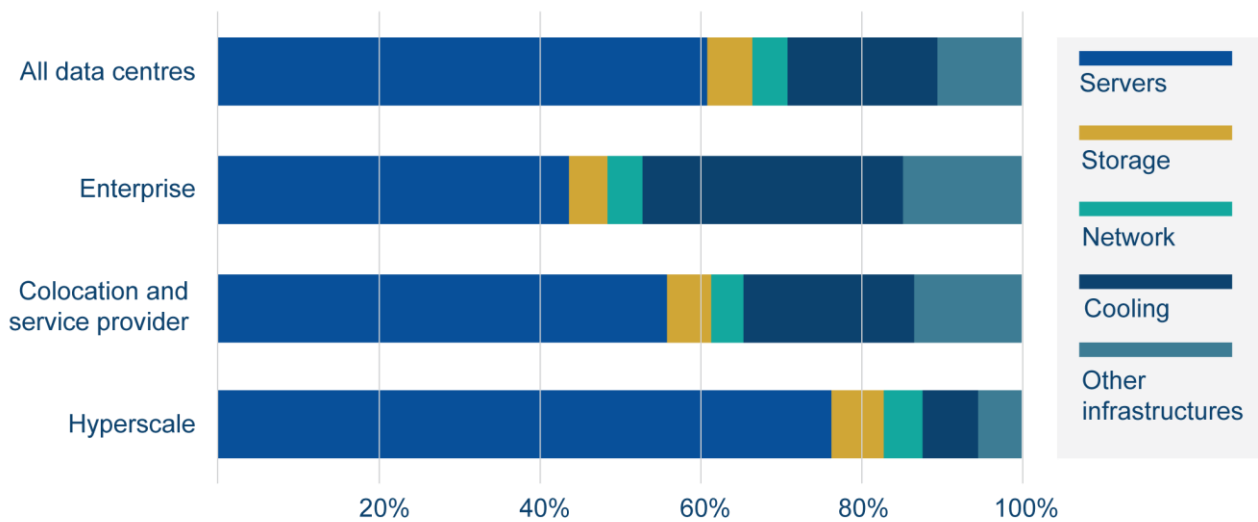
<sup>12</sup> [World Energy Outlook Special Report – Energy and AI](#), International Energy Agency (IEA), 2025; [2024 United States Data Center Energy Usage Report](#), Lawrence Berkeley National Laboratory, U.S. Department of Energy; [State of European Data Centres 2025](#), European Data Centre Association (EUDCA).

In this area, improvements can be made by operations managers who aim for most efficient use of the **energy provided for IT equipment** (computing, storage and networking) and also by IT project managers who want to **minimise resource consumption**. The following should be considered:

- **facilities management:** find ways to reduce energy consumption spent on non-IT equipment (including cooling, lighting and other), which in this example uses 40% of electricity;
- **operations management:** optimise IT consumption by deploying energy-efficient equipment, in particular, with capabilities to reduce consumption when idle;
- **IT project management:** work to optimise workload (i.e. IT resource consumption) by adopting efficient development techniques and aim to allocate resources more efficiently.

While the example in the previous page illustrates power consumption in an average enterprise data centre, these figures vary greatly among different types of data centres, as depicted in Figure 4 below, and depend largely on the energy efficiency of the equipment.

Figure 4 Share of electricity consumption by data centre and equipment type, 2024 <sup>13</sup>



<sup>13</sup> Adapted from [World Energy Outlook Special Report – Energy and AI](#), International Energy Agency (IEA), 2025, p. 53.

### 1.1.3. Site conditions influencing energy efficiency

From an energy performance standpoint, it must be taken into account that energy use and efficiency are also significantly influenced by the following factors:

- geographic location and local climate,
- data centre size and capacity,
- age of the data centre and IT equipment,
- infrastructure availability.

#### 1.1.3.1. Geographic location and local climate conditions

The geographic location of a data centre, specifically local climate and average temperatures, must be taken into account when comparing efficiency KPIs because weather variations are one of the most important factors influencing energy needed for the heating and cooling of buildings.<sup>14</sup>

As an illustrative example, this report compares two locations in France: the city of Toulouse in the southwest, and the north-eastern city of Strasbourg, where eu-LISA's data centre is located. Table 1 below provides a comparison between the two cities in terms of weather-based indicators for heating or cooling: **cooling degree days (CDD)** and **heating degree days (HDD)**, both calculated relative to a baseline temperature of 18°C, where

- **cooling degree days (CDD)**: indicate the need for cooling of buildings (i.e., air-conditioning) to maintain temperature above a given threshold; the higher the value, the more energy is needed;
- **heating degree days (HDD)**: indicate the need for internal heating required to maintain temperature above a given threshold; the higher the value, the more energy is required.

Table 1. HDD/CDD 18°C reference temperature in Toulouse and Strasbourg, France

location	HDD/CDD vs 18°C baseline temperature	2020	2021	2022	2023	2024	average degrees per year <sup>15</sup>
Toulouse-Blagnac	HDD (ref 18°C)	1642,9	1891,1	1622,5	1701,2	1686,5	1708,8
	CDD (ref 18°C)	678,8	561,9	988,2	870,1	612,7	742,3
Strasbourg-Entzheim	HDD (ref 18°C)	2413,2	2793,7	2357,1	2302,8	2355,4	2444,4
	CDD (ref 18°C)	491,9	348	599,6	574,3	458,8	494,5

Source: <https://www.infoclimat.fr/climatologie>

If free cooling is activated at outdoor temperatures below 18°C, then compared to Toulouse, the climatic conditions in Strasbourg over the past five years offered 43% more potential for free cooling (i.e., low outdoor temperatures), while also requiring 33.4% less mechanical cooling (i.e., hot weather outside).

#### 1.1.3.2. Data centre sizing

Even the most efficiently designed data centre will have poor energy performance if it is oversized and operates at only just a fraction of its maximum capacity. Precise **forecasting of actual needs for operational capacity** is not a trivial exercise, especially for on-premises data centres: the estimates must cover long-term projections and strategies can change very quickly. One way to mitigate these risks is to adopt **modular architectures**, enabling future **scalability** and the gradual addition of new capacity for power, cooling, and IT systems.<sup>16</sup>

<sup>14</sup> In a data centre context, '**free cooling**' refers to heat reduction technique utilising outside air that depends on external weather conditions, i.e. cooler temperatures.

<sup>15</sup> The number of total degrees, per year, that were compensated either with **internal cooling** (to maintain temperature below a given threshold) or **internal heating** (to maintain temperature above a given threshold), based on the difference between set threshold (18°C) and the average outside temperature per each day of the year.

<sup>16</sup> [International Review of Energy Efficiency in Data Centres](#), Australian Department of Industry, Science, and Resources, 2021.

### 1.1.3.3. Infrastructure availability

The availability of a data centre's infrastructure also has a significant impact on its performance because disruptions and downtime can have a negative effect on energy efficiency. Table 2 below provides a concise overview the **Tier classification**, developed by the Uptime Institute,<sup>17</sup> which offers a standardised ranking of data centre infrastructure based on **reliability, performance, and fault tolerance**.<sup>18</sup> The classification comprises four progressive tiers, each catering to different business needs and budgets, as outlined below.

Table 2. Tier classification for data centre site infrastructure

Tier classification for data centre site infrastructure	
<b>Tier 1</b>	<ul style="list-style-type: none"> <li>▪ most basic, offering a single path for power and cooling <b>without redundancy</b></li> <li>▪ guarantee 99.671% uptime annually, translating to less than 28.8 hours of downtime</li> <li>▪ suitable for small businesses or start-ups with simple IT requirements and limited budgets</li> </ul>
<b>Tier 2</b>	<ul style="list-style-type: none"> <li>▪ improve upon Tier 1 by <b>adding partial redundancy</b> for power and cooling components</li> <li>▪ provide 99.741% uptime, equating to less than 22 hours of downtime per year</li> <li>▪ ideal for small to medium-sized businesses seeking a cost-effective solution with better reliability</li> </ul>
<b>Tier 3</b>	<ul style="list-style-type: none"> <li>▪ concurrently maintainable, featuring multiple power and cooling paths and <b>full N+1 redundancy</b></li> <li>▪ ensure 99.982% uptime, with less than 1.6 hours of downtime annually</li> <li>▪ designed for large businesses with critical IT operations that require high availability</li> </ul>
<b>Tier 4</b>	<ul style="list-style-type: none"> <li>▪ fully fault-tolerant, with <b>2N or 2N+1 redundancy</b> for all components</li> <li>▪ guarantee 99.995% uptime, limiting downtime to less than 26.3 minutes per year</li> <li>▪ enterprises / government agencies w mission-critical operations and no tolerance for interruptions</li> </ul>

When selecting a data centre tier, organisations should balance their uptime requirements with their budget. Overinvesting in a higher tier can lead to unnecessary costs, while underinvesting can result in downtime that impacts productivity and satisfaction. As regards energy efficiency, when comparing data centres operating in the same region and with similar technologies, a Tier 4 data centre will generally be less energy efficient than Tier 3.

### 1.1.3.4. Data centre ageing

When it comes to ageing, it is important to separately consider the following two aspects:<sup>19</sup>

- **age of IT equipment:** the efficiency of electrical transformers, chillers, electrical engines installed 20 years ago is not comparable to modern ones, and performance naturally degrades over time. Since equipment has a limited lifetime, its **replacement** offers a great opportunity to select the more energy-efficient new equipment, aiming for cost-effectiveness. Indeed, as the equipment will eventually be replaced, only the financial difference between a basic solution and a more efficient one shall be considered when calculating the return on investment (ROI);
- **age of the data centre facility:** in the context of a **major refurbishment** where all facility equipment is within the scope of renewal, it is estimated that the cost of implementing a highly sustainable data centre is close to that of designing and implementing a new data centre. For the **renovation** of a data centre in which the server room is refurbished and new facilities are built from scratch to meet business requirements, the average cost is estimated between 10.000 and 15.000 €/m<sup>2</sup>, excluding IT equipment: servers, electronic bays, network, etc.

<sup>17</sup> [Uptime Institute](#) is globally recognised for the creation and administration of industry leading [tier standards and certification](#) for data centre design, construction, and operational sustainability.

<sup>18</sup> For more information, please refer to Uptime Institute's dedicated website on [Data Center Tier Classification](#).

<sup>19</sup> [International Review of Energy Efficiency in Data Centres](#), Australian Department of Industry, Energy and Resources, 2021.

## 1.2. DATA CENTRE ENERGY PERFORMANCE

In the context of data centres, energy efficiency relates primarily to how energy is sourced, used, and reused for the data centre facility and IT equipment. The improvement of energy performance starts from monitoring energy consumption. This is best done by establishing relevant KPIs and monitoring them over the long term to identify inefficiencies and implement targeted improvement measures. Regular monitoring enables to:

- **identify** deviations in energy consumption,
- **analyse** problems and identify root causes,
- **verify** recovery to a normal situation of operation after correction,
- **synchronise** energy consumption with computing capacity,
- **introduce** targeted measures to improve energy performance.

As regards data centres, the International Organization for Standardization (**ISO**) offers a holistic suite of **key performance indicators** (KPIs) for measuring data centre performance in terms of effectiveness and efficiency of using energy, as well as other critical resources, such as water and waste heat.<sup>20</sup> These KPIs, listed in Table 3 on the following page, promote the reduction of environmental impacts of data centres by way of

- **minimising** the consumption of **electricity and water**,
- using **renewable energy** (onsite/offsite), and
- **reusing** energy in the form of **waste heat**, if possible.

### ***Role of KPIs in improving energy performance***

The internationally verified and endorsed KPIs provide a comprehensive framework for tracking and managing data centre energy performance. Systematic monitoring of these KPIs enables data centre operators to improve energy performance over the long term, especially if these KPIs are integrated into broader organisational performance management systems, in particular:

- **energy management system** ensures systematic tracking of energy-related metrics and provides a comprehensive framework to guide improvement efforts in the long term;<sup>21</sup>
- **environmental management system** for improving overall sustainability by way of minimising the organisation's environmental impact. It provides a more **holistic approach** covering a wide range of aspects from resource use and waste management to monitoring environmental performance. Based on **life cycle assessment**, this framework considers the entire lifecycle of used products and services by requiring the evaluation of the **environmental footprint of the entire value chain**, in conjunction with setting reduction targets, and implementing action plans to improve performance.<sup>22</sup>

<sup>20</sup> [ISO/IEC 30134:2016](#) information technology — data centres — KPIs; adopted as European standard under [EN 50600:2019](#).

<sup>21</sup> [ISO 50001 standard](#) designed to support organisations in the development of an **energy management system** (EnMS).

<sup>22</sup> [ISO 14001 standard](#) for **environmental management systems** (EMS).

Table 3. ISO/IEC 30134:2016 series of standard KPIs for tracking data centre resource usage efficiency

<b>ISO/IEC 30134-1</b>	<b>overview and general requirements</b>
DESCRIPTION	sets conceptual framework, defines terminology, common requirements and objectives
<b>ISO/IEC 30134-2</b>	<b>power usage effectiveness (PUE)</b>
DEFINITION	ratio of total facility power to IT equipment power; assesses <b>energy efficiency</b>
DESCRIPTION	simple, intuitive metric; allows comparison between sites; considered ' <b>industry standard</b> '
<b>ISO/IEC 30134-3</b>	<b>renewable energy factor (REF)</b>
DEFINITION	proportion of renewable energy used in total data centre energy consumption
DESCRIPTION	aligns with sustainability goals and environmental regulations
<b>ISO/IEC 30134-4</b>	<b>IT equipment energy efficiency for servers (ITEEsv)</b>
DEFINITION	ratio of IT equipment energy use to total data centre energy use
DESCRIPTION	focuses on server/rack-level efficiency; less used due to reliance on specific hardware
<b>ISO/IEC 30134-5</b>	<b>IT equipment utilisation for servers (ITEUsv)</b>
DEFINITION	average utilisation rate of the IT equipment
DESCRIPTION	useful for internal optimisation; reflects how IT resources are actually utilised
<b>ISO/IEC 30134-6</b>	<b>energy reuse factor (ERF)</b>
DEFINITION	amount of energy reused externally compared to total consumed
DESCRIPTION	measures energy reused outside the data centre; relevant if excess heat/cooling is recovered
<b>ISO/IEC 30134-7</b>	<b>cooling efficiency ratio (CER)</b>
DEFINITION	ratio of total heat removed, and electrical energy used by a cooling system
DESCRIPTION	quantifies the efficient use of energy to control the temperature of spaces within a data centre
<b>ISO/IEC 30134-8</b>	<b>carbon usage effectiveness (CUE)</b>
DEFINITION	carbon emissions per unit of IT equipment energy consumption
DESCRIPTION	measures <b>direct GHG impact</b> ; aligns with carbon disclosure and climate action targets
<b>ISO/IEC 30134-9</b>	<b>water usage effectiveness (WUE)</b>
DEFINITION	volume of water used per unit of IT energy consumed
DESCRIPTION	important for water resource management; increasingly relevant in water-scarce regions

Considering that **legislation and industry standards** increasingly reference ISO metrics, and equivalent European standards, these KPIs provide a **comprehensive framework** for tracking data centre energy performance and offer a standardised foundation for compliance and reporting.

It is generally accepted that, out of the KPIs listed in the table above, the most relevant energy efficiency indicators are **PUE** and **WUE**. At the EU level, **REF** and the **ERF** are emerging as the two other main metrics to be reported by data centres operating in the EU.<sup>23</sup> These four indicators were also considered in a recent report exploring measures for the EU data centre energy efficiency rating scheme.<sup>24</sup> Further details about these four KPIs – PUE, WUE, REF and ERF – are provided in the following sections.

<sup>23</sup> Commission Delegated Regulation (EU) 2024/1364, [Annex III](#), and [2025 Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency](#), page 57.

<sup>24</sup> [Assessment of the energy performance and sustainability of data centres in EU: First technical report](#), EUDCEAR, European Commission, Directorate-General for Energy (DG ENER), July 2025.

### 1.2.1. Power usage effectiveness (PUE)

Introduced in 2006, power usage effectiveness (**PUE**) is a metric for determining how efficiently a data centre uses energy. Today, it is a widely adopted **industry standard** and the most commonly used KPI for reporting data centre energy efficiency.<sup>25</sup>

In 2016, PUE was included as a KPI in the **ISO/IEC 30134 series** laying down common requirements for data centre resource usage effectiveness and efficiency.<sup>26</sup> It has also been endorsed by the **EU Code of Conduct for Data Centres**,<sup>27</sup> and is reported under the **Energy Efficiency Directive** (EED) as part of EU's broader objective to achieve net zero emissions by 2050.<sup>28</sup>

PUE is calculated by dividing the **total annual electricity** consumed by data centre facility with the electricity consumed by its **IT equipment**, e.g., servers, storage, etc.

$$PUE = \frac{DC \text{ facility energy use (per year)}}{IT \text{ equipment energy use (per year)}}$$

In general, PUE values can range from the ideal 1.0 to higher. The lower the value, the higher the efficiency, i.e., value approaching 1.0 would indicate a perfectly efficient data centre where almost all power is used only by IT equipment.

On average, enterprise data centres report PUE values around 2 (i.e. 1 kWh of electricity used for cooling and auxiliary equipment for every 1 kWh of electricity used by IT equipment), whereas hyperscales are able to achieve values under 1.15 (i.e. 0.15 kWh used for cooling and auxiliary equipment for every 1 kWh used by IT equipment).<sup>29</sup>

#### **PUE as key international energy efficiency metric**

Over the years, industry professionals and organisations such as The Green Grid, Uptime Institute, as well as U.S. Department of Energy's Lawrence Berkeley National Lab (LBNL)<sup>30</sup> and National Renewable Energy Laboratory (NREL)<sup>31</sup>, have started using PUE reference values as metrics to evaluate data centre energy efficiency levels, as illustrated below in Table 4.

**Table 4. Data centre energy efficiency categories based on PUE reference values**

<b>PUE reference value range</b>	<b>data centre energy efficiency category</b>	<b>description</b>
<b>1,0</b>	<b>ideal</b>	theoretically perfect, practically unachievable
<b>≤ 1,2</b>	<b>very efficient</b>	state-of-the-art, newly built, advanced data centres (using liquid cooling etc.)
<b>≤ 1,3</b>	<b>efficient</b>	best-in-class modern data centres, strong efficiency measures in place
<b>≤ 1,5</b>	<b>average</b>	modern but standard efficiency, typical of older or mid-tier facilities
<b>≤ 2,0</b>	<b>inefficient</b>	older technology, lower efficiency, significant energy lost to infrastructure
<b>&gt; 2,0</b>	<b>very inefficient</b>	legacy data centres, outdated or poorly managed facilities

<sup>25</sup> Developed by [The Green Grid](#), a non-profit organisation focused on optimising energy and resource efficiency of data centres. For more information, please refer to the Green Grid white paper #49 [PUE™: A Comprehensive Examination of the Metric](#), 2012.

<sup>26</sup> [ISO/IEC 30134-2:2016](#), and also as European standard under [EN 50600-4-2:2016](#). The standard was **updated in 2026** and includes new guidance for mixed-use buildings, and greater clarity around on-site power generation.

<sup>27</sup> [2025 Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency](#), March 2025.

<sup>28</sup> Commission Delegated Regulation (EU) 2024/1364, [Annex III](#) on data centre sustainability indicators.

<sup>29</sup> [World Energy Outlook Special Report – Energy and AI](#), International Energy Agency (IEA), 2025, p. 54.

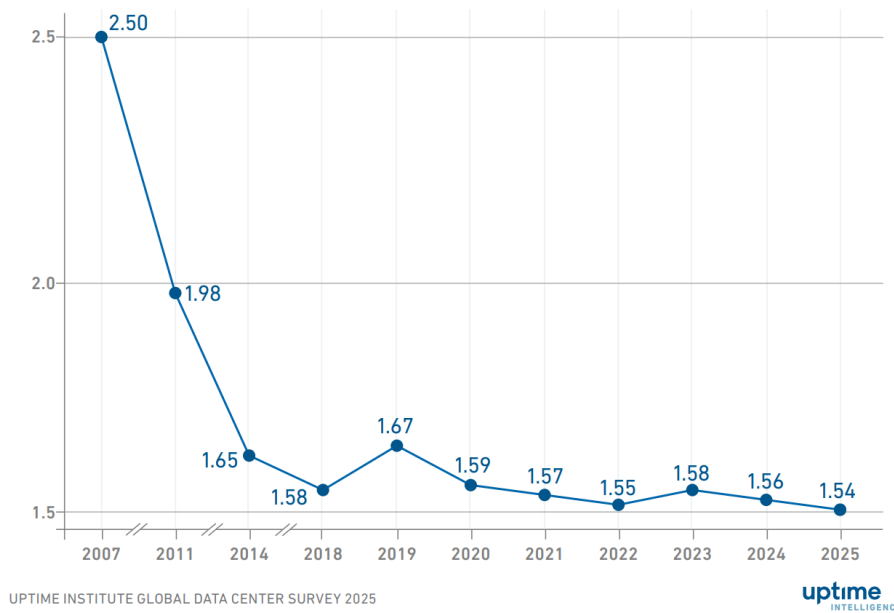
<sup>30</sup> [Lawrence Berkeley National Lab](#) (LBNL) under Federal Energy Management Program (FEMP), U.S. Department of Energy (DoE).

<sup>31</sup> [National Renewable Energy Laboratory](#) (NREL) under the U.S. Department of Energy (DoE).

Since the introduction of PUE in 2006, early guidance and industry practice used  $\approx 1.2$  as ‘best-in-class’ and  $\geq 2.5$  as ‘poor’. In 2012, PUE guidance referenced 1.2 as ‘excellent’, with at least 1.6 achievable with good design.<sup>32</sup> By 2015, hyperscalers reported fleet PUE at  $\approx 1.1$ -1.2; while industry averages remained higher around  $\sim 1.6$ -1.8. Around 2020, modern hyperscaler facilities continued to achieve  $\approx 1.1$ , while overall industry average was reported at  $\sim 1.55$ –1.8, moving the ‘average’ band downward compared to earlier years.<sup>33</sup> Most recent industry surveys treat  $\leq 1.2$  as ‘excellent’; with leading hyperscalers achieving ‘very efficient’ at  $\leq 1.10$ .<sup>34</sup>

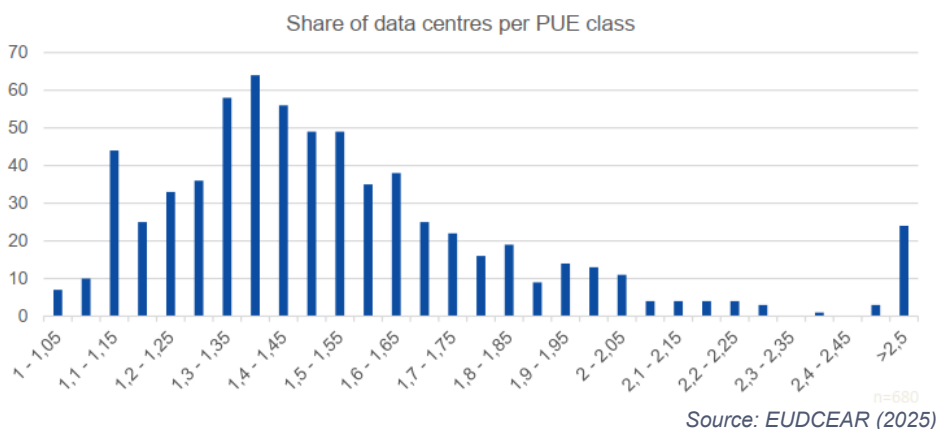
In 2025, the **global average** annual PUE stood at **1.54**, according to a worldwide survey of data centre owners and operators<sup>35</sup> Hyperscalers and major cloud service providers claim to be positioned in the 1.2 to 1.3 range, which is not independently verifiable, but believed to be credible.

Figure 5. Global average annual PUE of data centres, 2007-2025



According to a recent EU report, in 2024, the majority of **European data centres** were concentrated in the 1.1 to 2.0 range, with an **average PUE of 1.36**, while some still report values above 2.0, as shown in Figure 6 below. As recommended in the report, data centres reporting values below 1.05 or above 2.5 should be reviewed, as those figures could be not realistic or not properly computed.<sup>36</sup>

Figure 6. EU reporting scheme: PUE values of European data centres, 2024



<sup>32</sup> *PUE™: A Comprehensive Examination of the Metric*, 2012, The Green Grid white paper #49.

<sup>33</sup> *Large data centers are mostly more efficient, analysis confirms*, Uptime Institute, blog post 7 February 2024.

<sup>34</sup> *Best Practices Guide for Energy-Efficient Data Center Design*, Federal Energy Management Program (FEMP), DoE, July 2024.

<sup>35</sup> *Uptime Institute Global Data Center Survey Results 2025*.

<sup>36</sup> *Assessment of the energy performance and sustainability of data centres in EU*, EUDCEAR, July 2025, pp.31-38.

### **Advantages and limitations of using PUE**

An excellent overview of PUE usage can be found in a literature review published by the European Heating, Ventilation and Air Conditioning Associations (REHVA),<sup>37</sup> and further elaborated in a 2021 report published by the Australian government,<sup>38</sup> which includes a comprehensive international review of energy efficiency in data centres. Table 5 below summarises the advantages and limitations of using PUE based on the information provided in those sources.

**Table 5. Advantages and limitations of using PUE**

<b>ADVANTAGES of using PUE</b>
<p>PUE has emerged as the number one KPI to measure the energy efficiency of data centres as it shows the efficiency not by quantifying useful work, but by showing the <b>ratio of energy available for useful work</b> and the part that is lost to overhead, also referred to as the infrastructure. As a result, PUE has been widely adopted by the industry as the main performance metric, primarily due to its success at focusing attention on and reducing infrastructure energy use.</p> <p>As stated in the ISO/IEC 30134-2 standard, PUE provides effective guidance for:</p> <ul style="list-style-type: none"> <li>▪ the <b>design of efficient power and cooling architectures</b>,</li> <li>▪ the <b>deployment and operation of equipment</b> within those architectures.</li> </ul> <p>PUE provides a means to determine:</p> <ul style="list-style-type: none"> <li>▪ opportunities for <b>improving the operational efficiency</b> of a data centre,</li> <li>▪ the improvement of <b>data centre design and processes</b> over time, and</li> <li>▪ a <b>design target</b> or goal for new data centres across the anticipated IT load range.</li> </ul>
<b>LIMITATIONS of using PUE</b>
<p>Although PUE is useful for improving the energy efficiency of data centres, it does not provide an adequate reflection of overall energy, productivity or resource efficiency of a data centre.</p> <p>Thus, while PUE is a reasonable and useful metric for assessing the infrastructure efficiency of a data centre, it is <b>not a comprehensive metric</b>, and relying only on PUE values does not provide a truly meaningful picture of data center performance.</p> <p>In short, PUE's limitations are due to the fact that it does not take into account:</p> <ul style="list-style-type: none"> <li>▪ IT load utilisation or productivity,</li> <li>▪ efficiency of on-site electricity generation,</li> <li>▪ efficiency of other resources such as human resource, space or water, and</li> <li>▪ use of renewable energy resources or accounts for re-use of waste by-products (such as heat).</li> </ul>

Due to these shortcomings, additional metrics have been developed to provide a more holistic approach to evaluating energy efficiency, such as **renewable energy factor** (REF) and **energy reuse factor** (ERF), as well as others listed in Table 3 on page 19. Those metrics focus on other specific aspects of energy efficiency and are recommended to be used as complementary to PUE in order to gain a more comprehensive insight into overall energy efficiency. However, finding a metric for IT productivity that is robust and practical has proved difficult and is still unsolved, although PUE is probably the closest the community has provided so far.

<sup>37</sup> [Analysis of performance metrics for data center efficiency – should PUE still be used as the main indicator? \(Part 1\)](#), Federation of European Heating, Ventilation and Air Conditioning Associations ([REHVA](#)), 2017.

<sup>38</sup> [International Review of Energy Efficiency in Data Centres](#), Australian Department of Industry, Science, and Resources, 2021.

### ***Setting and monitoring PUE performance targets***

It should be taken into account that for a new data centre, and also after a major refurbishment, a gap frequently occurs between the performance estimated at the design level and **actual operational performance**. For example, a data centre designed for a 1.3 PUE frequently reaches only 1.4 PUE when operational. This could be explained by the following factors:

- blanking panels and containment are not fully deployed,
- servers are mounted in clusters where hotspots occur,
- computer room air handling (CRAH) units and chillers need to operate at higher power compared to the design,
- data centre is not fully populated from day one, meaning that there may be over-dimensioned components both in the power distribution and heat rejection chain that are not working in their optimal performance range.

To avoid such gaps, it is recommended to:

- **specify required PUE performance levels** in technical requirements and include contractual clauses with significant financial penalties if these levels are not achieved in operation. The conditions and means for measuring performance must be precise, and must take into account local climate variations across the year, incl. adjusted for cooling degree days;
- **verify achieved performance** with real measurement and test before delivery: electrical variable resistive load banks can be racked simulating servers, to enable verification of PUE curve as a function of the IT equipment load. Considering that PUE is calculated over the entire year, tests should be done before delivery and adjusted using thermal simulation to represent a full year, even when free cooling is not possible. Alternatively, system-wide software simulations can also provide useful estimates of the annual average PUE.

### 1.2.2. Renewable energy factor (REF)

REF is a metric to track the share of renewable energy used in total data centre energy consumption. It was published in 2016 as part of the initial set of KPIs under the **ISO/IEC 30134 series** laying down common requirements for data centre resource usage effectiveness and efficiency.<sup>39</sup> REF has also been endorsed by the EU and is reported under the Energy Efficiency Directive (EED).<sup>40</sup>

As a KPI, REF facilitates the diversification of energy procurement, with a view to reducing dependence on non-renewable sources of energy, while also linking to broader decarbonisation targets and strategies, including sustainability reporting.

REF is calculated by dividing the amount of energy supplied from renewable energy sources with the total energy consumed by the data centre. It is usually expressed either as a ratio on a scale from 0 to 1, or as a percentage. The higher the value – close to 1 or 100%, the higher the share of renewables in the energy mix.

$$REF = \frac{\text{renewable energy use}}{\text{total energy consumption}}$$

Currently, there is no globally binding regulatory classification of data centres based on REF values; however, industry and various sustainability frameworks typically interpret REF ranges as follows:

**Table 6. Data centre energy efficiency categories based on REF reference values** <sup>41</sup>

REF reference value range	data centre energy efficiency level	description
90-100 %	excellent	leading sustainable data centre
70-89 %	very good	strong renewable integration
40-69 %	moderate	transitioning
<39 %	poor	low renewable share

#### **Sources of renewable energy counting toward REF**

Generally, solar, wind, hydropower, geothermal energy, and sustainable biomass/biogas are considered as sources of renewable energy, whereas natural gas, coal, oil, nuclear power (low carbon, but not renewable) are not included as renewable in REF computation. Also excluded from REF is the **recovery and/or reuse of waste heat**, which counts toward energy efficiency, but does not factor into increasing the share of renewable energy. Waste heat reuse is measured by a separate KPI – energy reuse factor (**ERF**) – covered in the following section.

Typically, there are three procurement pathways for renewable energy:

- **on-site generation** of renewable energy, e.g., solar energy, fuel cells, etc.,
- energy purchased via **power purchase agreements (PPAs)**,
- guarantees of origin (GoO) or renewable energy certificates (REC).

When calculating REF, it is important to bear in mind that it covers only **certifiable renewable energy** that is either purchased from service providers, or produced and also consumed on site. The latter distinction means that REF excludes any renewable energy that is generated on site but not consumed there and sold to the grid instead.<sup>42</sup> For more information about **on-site generation of renewable energy**, please refer to section 5.2. on page 71.

<sup>39</sup> [ISO/IEC 30134-3:2016](#), and also as equivalent European standard under [EN 50600-4-3:2016](#).

<sup>40</sup> Commission Delegated Regulation (EU) 2024/1364, [Annex III](#) on data centre sustainability indicators.

<sup>41</sup> [Renewables represent 87% of energy consumption in EU data centres](#), International Institute of Refrigeration (*IIR*), December 2025, as reported in [Assessment of the energy performance and sustainability of data centres in EU](#), EUDCEAR, July 2025.

<sup>42</sup> [2025 Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency](#), p. 13.

### 1.2.3. Energy reuse factor (ERF)

ERF measures the amount of energy that is generated in a data centre as a result of excess heat or cooling and then **reused for an alternative purpose outside** the data centre, e.g., integrated into district heating systems.<sup>43</sup> A relatively new metric, ERF was added to the ISO/IEC 30134 series in 2021, and is reported under the EU's Energy Efficiency Directive (EED).<sup>44</sup>

ERF is calculated by dividing the amount of reused energy with the total energy consumed by the data centre. In this context, '*reused energy*' refers to the **energy exported** (typically in the form of excess heat) from the data centre to be used for other purposes, e.g., in district heating systems.

$$ERF = \frac{\text{reused energy}}{\text{total energy consumption}}$$

In this regard it is important to stress that the heat reused internally within the data centre does not count toward ERF. In order for the energy to count as '*reused energy*' it must be:

- exported beyond the data centre boundary,
- used beneficially, i.e., not wasted,
- measurable and documented.

Common examples of this kind of energy reuse, also referred to as '*waste heat valorisation*', include supplying excess heat to district heating networks, heating nearby residential or commercial buildings (incl. own office space), supplying heat to agricultural use (e.g., greenhouses), and industrial process heat recovery. As such, its impact on the data centre's own energy performance is less significant than its contribution to improving the efficiency of the overall energy system at a broader societal level. For more information about **waste heat valorisation**, please refer to section 3.2.2. on page 52.

Similarly to renewable energy factor (REF), there is no strict classification linked to this indicator. However, based on industry practice, ERF values can be broadly categorised as follows:

**Table 7. Data centre energy efficiency categories based on ERF reference values** <sup>45</sup>

ERF reference value range	data centre energy efficiency level	description
0.5 - 0.8+	very high energy reuse	excellent/leading sustainability level
0.2 - 0.49	significant reuse	good sustainability level
0.05 - 0.19	limited reuse	moderate sustainability level
0 - 0.04	minimal or no reuse	poor/typical sustainability level

Currently, most conventional data centres report ERF equal or very close to 0, meaning that practically no excess heat is reused and ends up wasted. At the same time, high-performance data centres or those integrated into district heating systems are reporting ERF around 0.3-0.6, while some exceptional urban-integrated examples may even exceed 0.7.

In general, achieving higher levels of ERF usually requires liquid cooling, high outlet temperatures, urban location near heat demand, and infrastructure for district heating.

<sup>43</sup> [ISO/IEC 30134-6:2021](#), and also as equivalent European standard under [EN 50600-4-6:2000](#).

<sup>44</sup> Commission Delegated Regulation (EU) 2024/1364, [Annex III](#) on data centre sustainability indicators.

<sup>45</sup> As reported in [Assessment of the energy performance and sustainability of data centres in EU: First technical report](#), European Commission: Directorate-General for Energy, AIT, Borderstep and EY, July 2025.

### 1.2.4. Water usage effectiveness (WUE)

Published in 2022, WUE is the most recent KPI added to the **ISO/IEC 30134 series** laying down common requirements for KPIs related to data centre resource usage effectiveness and efficiency,<sup>46</sup> and it has also been endorsed by the EU as a mandatory metric to be reported under the EED.<sup>47</sup>

WUE measures data centre's resource effectiveness in terms of **water consumption** caused by the processing of data and also the performance of its **cooling installation** by tracking the volume of water used per unit of energy consumed by IT equipment. With the exponential growth of data centres, the impact of operational water usage is emerging as a significant factor in the design, location and operation of data centres.

WUE is calculated by dividing the data centre's total water use (m<sup>3</sup>) with the energy consumed by the IT equipment (MWh).<sup>48</sup>

$$WUE = \frac{\text{water consumed by DC facility (m3)}}{\text{energy consumed by IT equipment (MWh)}}$$

As per ISO definition, water usage covers all consumption caused by data processing, including water loops, cooling towers, humidification, etc. While this definition is site-based, the water needed for the production of energy that powers the data centre is a different matter depending on local conditions and much more complex to consider.

The following values are commonly considered as industry reference ranges:

Table 8. Data centre energy efficiency categories based on WUE reference values<sup>49</sup>

WUE reference value ranges	data centre energy efficiency category	data centre type
≤ 0,10 m <sup>3</sup> /MWh	best-in-class	hyperscalers (e.g. Google, Microsoft, Meta), with advanced liquid or air cooling
0,10 – 0,50 m <sup>3</sup> /MWh	efficient / modern average	large colocations, newer builds
0,50 – 1,80 m <sup>3</sup> /MWh	typical older facilities	with cooling towers, less optimisation
> 1,8 m <sup>3</sup> /MWh	inefficient	high water dependence, hot climates

While traditional discussions related to data centre efficiency focus primarily on the consumption of electricity, water usage has been garnering increasing attention due to concerns about **water scarcity** and environmental sustainability, particularly considering the growing scale of data centre operations undertaken by hyperscalers. As a result, WUE is also becoming an important indicator of data centre sustainability alongside PUE.

One of the main advantages of WUE is that it highlights the often-overlooked environmental impact of water consumption in data centre **cooling systems**. By quantifying water usage relative to computing activity, the metric allows operators to compare the water usage efficiency of different cooling technologies and operational strategies. WUE can therefore support more informed decision-making with regard to infrastructure design, encourage the adoption of water-efficient cooling technologies, and promote transparency in sustainability reporting. Additionally, WUE complements energy-focused metrics such as PUE, enabling a broader evaluation of environmental performance that considers both energy and water resources.

<sup>46</sup> [ISO/IEC 30134-9:2022](#), and also as equivalent European standard under [EN 50600-4-9:2022](#).

<sup>47</sup> Commission Delegated Regulation (EU) 2024/1364, [Annex III](#) on data centre sustainability indicators.

<sup>48</sup> While ISO defines WUE in terms of m<sup>3</sup>/MWh, it is also quite common to find it reported in terms of the equivalent unit litres/kWh.

<sup>49</sup> Sources: [Uptime Institute](#), Lawrence Berkeley National Lab ([LBNL](#)), National Renewable Energy Laboratory ([NREL](#)).

However, WUE also has several **limitations** as a standalone sustainability indicator:

- it does not capture the availability or scarcity of **local water resources**, meaning that the same WUE value may have very different environmental implications depending on the geographic location of the data centre;
- WUE focuses only on direct water consumption and may not account for **indirect water use** embedded in electricity generation or other parts of the infrastructure lifecycle;
- optimising solely for WUE could lead to **trade-offs with energy consumption**; for example, some cooling solutions that minimise water consumption may require higher electricity use.

For these reasons, WUE is generally most useful when applied together with other indicators – such as PUE, REF and ERF – to provide a more comprehensive assessment of data centre sustainability.

# *REGULATORY FRAMEWORKS FOR ENERGY EFFICIENCY*



## 2. REGULATORY FRAMEWORKS FOR ENERGY EFFICIENCY

Due to their significant role as the backbone of modern digital societies, coupled with increasing energy consumption, data centres have become the focus of targeted policy instruments designed to improve transparency through environmental reporting, and drive continuous improvement in energy efficiency and promote sustainability across the IT value chain.

This section provides a structured review of relevant regulatory frameworks that directly or indirectly impact energy performance of data centres, covering:

- **EU frameworks**, including both binding legal obligations and voluntary initiatives;
- and a concise overview of **international efforts**, highlighting selected examples from countries, such as **U.S., Japan and China**, where national standards already impose concrete efficiency targets and reporting obligations on data centres specifically.

These policy frameworks serve both as a catalyst and a compass, **raising the bar for collective ambition** and accelerating innovation for energy efficiency throughout the data centre value chain.

### 2.1. EUROPEAN UNION

**2.1.1. Energy efficiency** and common rating scheme for data centres

**2.1.2. Ecodesign** requirements for servers and data storage products

**2.1.3. Energy performance of data centre facilities**

**2.1.4. Renewable energy** use

2.1.5. European **best practice frameworks** and voluntary guidelines

### 2.2. INTERNATIONAL OUTLOOK

**2.2.1. International best practice frameworks** and voluntary guidelines

**2.2.2. Regulatory framework in the United States of America**

**2.2.3. Regulatory framework in Japan**

**2.2.4. Regulatory framework in China**

## 2.1. EUROPEAN UNION

At the European level, the performance of data centres falls under of several broader policy initiatives. On the one hand, the **EU's Digital Decade policy programme 2030** lays out the common objectives and targets for Europe's digital transformation, with the topic of data centres falling under the objective of secure and **sustainable digital infrastructures**.<sup>50</sup> This includes promoting research focused on measuring the impact of digital technologies, as well as developing sustainable and energy efficient innovations, which are highlighted in section 3.2. on page 51 of this report.

However, the topics related to data centres fall primarily under the **European Green Deal**, which sets the ambitious goal of achieving **climate neutrality by 2050** and transitioning to a **circular economy** model. This includes a comprehensive transformation of Europe's economy, energy systems, transport, and industries toward more **resource-efficient and sustainable** future.<sup>51</sup>

*Digital technologies are a **critical enabler** for attaining the sustainability goals of the Green Deal [...] Europe needs a digital sector that puts sustainability at its heart, in particular measures to improve the **energy efficiency and circular economy** performance, [...] as well as improving transparency on their environmental impact.*<sup>52</sup>

### **European Climate Law**

In 2021, to ensure that all EU policies contribute to the strategic objectives outlined in the Green Deal, the climate neutrality targets were made legally binding for all EU Member States with the adoption of the **European Climate Law**.<sup>53</sup> To achieve the 2050 climate neutrality target of net zero greenhouse gas (GHG) emissions, the law sets intermediate targets to reduce emissions by at least **55% by 2030** (Fit for 55 legislative package), and by **90% by 2040**.<sup>54</sup>

These climate targets cover all key sectors of the economy, and focus primarily on cutting emissions (decarbonisation) by investing in clean technologies, green infrastructure, and renewable energy.<sup>55</sup> While the law establishes overarching strategic directions and principles, specific obligations for data centres are set out in subsequent implementing acts.

### **REPowerEU plan**

Energy efficiency is a key priority, taking guidance from the Commission's '**energy efficiency first**' principle. This approach prioritises energy efficiency considerations in decision-making across a wide range of policy objectives. Under the EU's energy policy strategy REPowerEU, this effort focuses on the diversification of energy supply to reduce dependence on fossil fuels.<sup>56</sup> To that end, the following binding targets have been set for 2030:

- increase **renewable energy** use to a minimum of **42.5%** (with the ambition to reach 45%),
- improve **energy efficiency** by **11.7%**.<sup>57</sup>

<sup>50</sup> [EU Digital Decade policy programme 2030](#) promotes sustainable digital transformation, with a focus on digital infrastructures.

<sup>51</sup> For a more detailed overview, please refer to the Commissions dedicated website on the [European Green Deal](#).

<sup>52</sup> Commission Communication on [The European Green Deal](#), 11 December 2019, COM(2019) 640 final.

<sup>53</sup> For a more detailed overview, please refer to the Commissions dedicated website on the [European Climate Law](#).

<sup>54</sup> For more, please visit the Commission's dedicated website on the [Fit for 55 legislative package](#), and the [2040 climate target](#).

<sup>55</sup> Targeted initiatives include [Green Deal Industrial Plan](#); [Critical Raw Materials Act](#); [Net-Zero Industry Act](#); etc.

<sup>56</sup> For more, please visit the Commission's dedicated websites on the [REPowerEU plan](#).

<sup>57</sup> For more, please visit the Commission's dedicated website on [renewable energy targets](#) and [energy efficiency targets](#).

## Regulatory instruments to improve energy efficiency

The following table lists the key EU instruments that pertain to data centres, establishing technical requirements for IT infrastructure and equipment, as well as specific obligations to improve energy efficiency in data centre facilities and increase the share of renewables in the power supply mix.

**Table 9. EU regulatory framework for improving energy efficiency in data centres**

relevance to data centres	key provisions affecting data centres
<b>Energy Efficiency Directive (EED)</b>	
introduces reporting obligations and energy performance metrics for data centres, further specified in the Commission Delegated Regulation establishing a common EU rating scheme for data centres	
<b>data centres with IT energy demand of at least 500kW</b>	<ul style="list-style-type: none"> <li>mandatory reporting of energy consumption and sustainability indicators</li> <li>creation of a European database for tracking energy performance</li> <li>promotes resource efficiency, renewable energy and waste heat recovery</li> </ul>
<b>Ecodesign Framework Directive =&gt; <i>Ecodesign of Sustainable Products Regulation (ESPR)</i></b>	
covers energy-related products used in data centres (e.g., servers, data storage), is in the process of being replaced by ESPR, which expands the ecodesign framework to a wider scope	
<b>energy-related products used in data centres</b>	<ul style="list-style-type: none"> <li>establishes minimum energy performance requirements for products used in data centres (via implementing acts covering specific product categories)</li> <li>encourages energy efficiency improvements across the entire lifecycle</li> </ul>
<b>Energy Performance of Buildings Directive (EPBD)</b>	
establishes 'zero-emission buildings' as a new standard; non-residential buildings that host the technical infrastructure and IT equipment of data centres must also improve their overall energy performance	
<b>data centre facilities as non-residential buildings</b>	<ul style="list-style-type: none"> <li>minimum energy performance standards for non-residential buildings</li> <li>renovation of existing facilities</li> <li>promotes shift towards renewable energy sources</li> </ul>
<b>Renewable Energy Directive (RED III)</b>	
promotes the use of renewable energy across all sectors of the economy, and introduces provisions that are relevant to large electricity consumers such as data centres	
<b>indirect impact via energy supply</b>	<ul style="list-style-type: none"> <li>supports corporate renewable electricity sourcing via power purchase agreements, and on-site generation relevant for data centre operators</li> <li>integrating waste heat into district heating systems</li> </ul>

In addition to sector-specific instruments, broader EU frameworks, such as the **Corporate Sustainability Reporting Directive (CSRD)**<sup>58</sup> and the associated **European Sustainability Reporting Standards (ESRS)**,<sup>59</sup> require large companies, including cloud and infrastructure providers, to disclose standardised information on their environmental and energy performance. While not specific to data centres, these frameworks reinforce the reporting logic introduced by sectoral regulations and support alignment with broader sustainability goals.

<sup>58</sup> [Directive \(EU\) 2022/2464](#) as regards corporate sustainability reporting (**CSRD**).

<sup>59</sup> [Commission Delegated Regulation \(EU\) 2023/2772](#) as regards European Sustainability Reporting Standards (**ESRS**).

## 2.1.1. Energy efficiency and common rating scheme for data centres

### Energy Efficiency Directive (EED)

Entered into force on 10 October 2023 and fully applicable as of 11 October 2025 after transposition into national law, EED sets **binding targets** to be achieved by 2030, including an EU-wide target to improve energy efficiency by 11,7%.<sup>60</sup>

As regards data centres, **energy performance reporting obligations** are imposed on owners and operators whose IT infrastructures have an electrical demand of at least 500 kW, regardless of ownership or operator type.<sup>61</sup>

### Common EU rating scheme for data centres

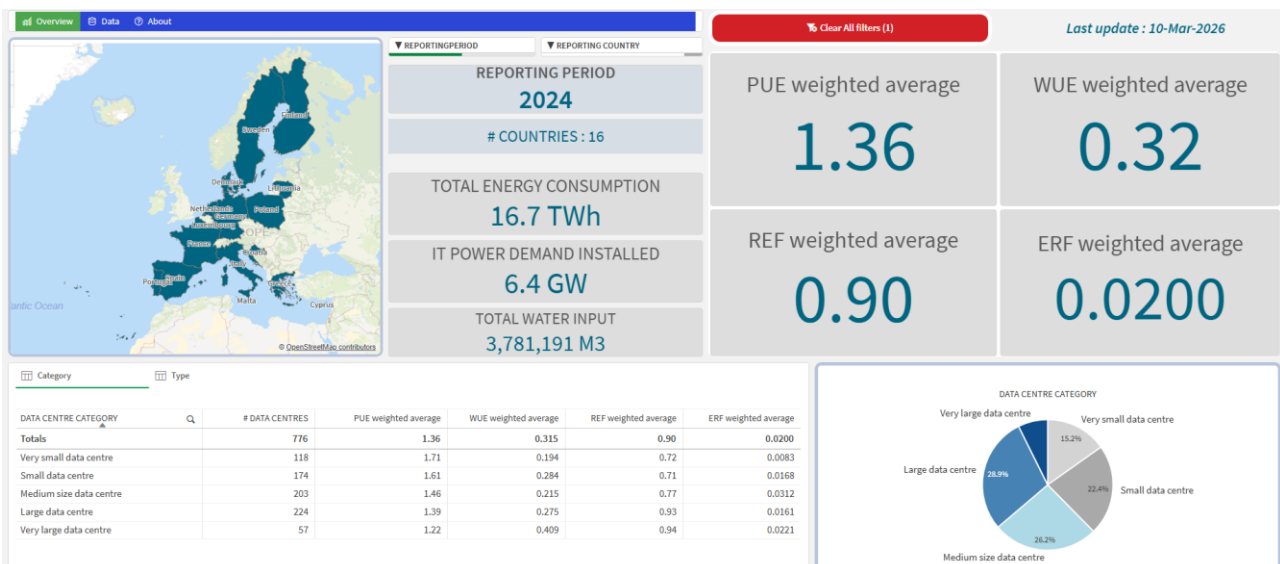
The reporting obligations stemming from the EED are further detailed in the Commission Delegated Regulation establishing the first phase of a common EU rating scheme for data centres, adopted in March 2024.<sup>62</sup>

This regulation defines the **reporting methodology** and sustainability indicators to be reported annually to a **dedicated EU database**, benchmarking data centre energy performance across the EU.<sup>63</sup> Figure 7 below depicts the online dashboard where aggregated statistics are publicly shared as of 2025.<sup>64</sup>

Energy efficiency indicators	
✓	<b>total energy consumption</b> (MWh)
✓	energy mix used, including share of <b>renewable energy</b>
✓	inlet temperature and humidity in server rooms ( <b>cooling setpoints</b> )
✓	<b>water consumption</b> for cooling (m <sup>3</sup> )
✓	<b>waste heat reuse</b> (qualitative and quantitative in kWh, <i>if applicable</i> )

Reported energy efficiency KPIs	
✓	power usage effectiveness ( <b>PUE</b> )
✓	water usage effectiveness ( <b>WUE</b> )
✓	renewable energy factor ( <b>REF</b> )
✓	energy reuse factor ( <b>ERF</b> )
✓	inlet temperature and humidity levels ( <b>cooling setpoints</b> )

Figure 7. EU dashboard on data centre energy efficiency (screenshot 20 April 2026)



These reporting obligations represent the first step towards developing a more comprehensive set of requirements for data centres operating in the EU. Recognising the rapidly growing importance of

<sup>60</sup> Directive (EU) 2023/1791 on energy efficiency (EED) and amending Regulation (EU) 2023/955 (recast), September 2023.

<sup>61</sup> In particular Article 12 of the Energy Efficiency Directive (EED).

<sup>62</sup> Commission Delegated Regulation (EU) 2024/1364 on first phase of establishing a common EU rating scheme for data centres.

<sup>63</sup> Data centre sustainability indicators are further elaborated in Annex III of Commission Delegated Regulation (EU) 2024/1364.

<sup>64</sup> For aggregate statistics, please refer to EU's [data centre reporting dashboard](#). For more information, please refer to the Commission's dedicated website on [energy performance of data centres](#).

data centres within the global digital economy, the Commission is set to further evolve this framework to increase transparency regarding the environmental impact of digital infrastructure.

Building on input from stakeholders and two reporting cycles under the EED, the Commission is preparing to put forward a **data centre energy efficiency package** that is expected to introduce **minimum performance standards** (MPS), together with a **labelling scheme** for data centres.<sup>65</sup> This effort is supported by research carried out by **EUDCEAR** on the development of performance standards that can be enforced consistently across the EU.<sup>66</sup>

## FURTHER READING

**EUDCEAR** reports on the EU's common data centre rating scheme:

- [Assessment of the energy performance and sustainability of data centres in EU](#), July 2025
- [Assessment of next steps to promote the energy performance and sustainability of data centres in EU, including the establishment of an EU-wide rating scheme](#), October 2025

### 2.1.2. Ecodesign requirements for servers and data storage products

Adopted in 2009, the **Ecodesign Framework Directive** established a framework for setting minimum performance requirements for **energy-related products** sold in the EU.<sup>67</sup> This framework has been implemented through product-specific regulations, and for data centres, these requirements are detailed in a ecodesign regulation for **servers and data storage products**.<sup>68</sup>

Although it does not apply directly to data centre operators – only to product **manufacturers and importers** – by defining **minimum performance standards** for new servers and storage equipment, it directly affects all data centres that purchase new equipment, as products not complying with these requirements cannot be sold in the EU.

As such, the Regulation directly shapes the **baseline energy and cooling efficiency of IT infrastructure**, while also indicating what can be achieved through hardware compliance, feeding into more **informed procurement**, and **lifecycle planning** in alignment with broader sustainability goals. As of July 2024, the Ecodesign Directive is in the process of being phased out by the new **Ecodesign Regulation** (ESPR),<sup>69</sup> that extends the scope of the ecodesign framework to cover virtually all physical products, rather than only energy-related products as was the case with the directive. Implementing acts adopted under the directive will remain in force until they are repealed.<sup>70</sup>

Ecodesign requirements for IT equipment	
<b>1. power supply efficiency</b>	minimum required levels, at nominal input voltage <ul style="list-style-type: none"> <li>▪ at 10% load: ≥ 84%</li> <li>▪ at 20% load: ≥ 90%</li> <li>▪ at 50% load: ≥ 92%</li> <li>▪ at 100% load: ≥ 89%</li> </ul>
<b>2. idle power limits</b>	<ul style="list-style-type: none"> <li>▪ single-socket servers: ≥ 30 w</li> <li>▪ dual-socket servers: ≥ 50 w</li> </ul>
<b>3. information/documentation requirements</b>	<ul style="list-style-type: none"> <li>▪ list of key components (for repair/reuse)</li> <li>▪ operating conditions and idle power declaration</li> <li>▪ secure data deletion functionality</li> <li>▪ access to firmware updates</li> </ul>
<b>4. design for circularity</b>	<ul style="list-style-type: none"> <li>▪ disassembly of components with common tools, e.g. memory, storage, power supply</li> <li>▪ avoidance of glued/welded parts that restrict reuse/recycling</li> </ul>

<sup>65</sup> The Commission's Directorate-General for Energy (DG ENER): [Energy performance of data centres: next steps](#).

<sup>66</sup> [EUDCEAR](#) study commissioned by DG ENER to explore measures for the EU data centre energy efficiency rating scheme, is now focusing on the development of [minimum performance standards](#) (MPS) for data centres.

<sup>67</sup> [Directive 2009/125/EC](#) establishing a framework for the setting of **ecodesign requirements for energy-related products**.

<sup>68</sup> [Commission Regulation \(EU\) 2019/424](#) on ecodesign requirements for **servers and data storage products**.

<sup>69</sup> [Regulation \(EU\) 2024/1781](#) establishing a framework for ecodesign requirements for sustainable products (**ESPR**).

<sup>70</sup> For more on the **gradual phase-out** of the Ecodesign Directive, please refer to the Commission's [dedicated website](#).

## **Reducing environmental impact at the level of design**

Closely related to the energy efficiency of data centres is the **broader concept of ecodesign**, which refers to the **integration of environmental considerations** into the design, manufacturing, and operation of data centre equipment and infrastructure throughout their **entire lifecycle**. In February 2026, ISO published a **new international standard** on the ecodesign of digital services, covering the **entire lifecycle**, from requirements gathering and design through implementation, operation and maintenance until final disposal at the end of life. The standard establishes requirements for operational efficiency and minimising the adverse environmental impacts, such as greenhouse gas emissions and the depletion of critical raw materials.<sup>71</sup>

Ecodesign and life cycle assessment (LCA) are at the core of circular economy, whose proponents estimate that around **80% of a product's environmental impact is determined during the design phase**, while the remaining 20% is addressed through operational optimisation.<sup>72</sup> By addressing both product-level efficiency and system-level optimisation, ecodesign contributes to **reducing the environmental footprint of digital infrastructure** while supporting the **long-term resource efficiency and sustainability** of rapidly expanding data centres.

Within the data centre sector, ecodesign principles are **applied primarily to IT equipment** such as servers, storage devices, and power supplies, with the objective of reducing energy consumption and improving performance, as well as minimising environmental impacts during manufacturing, operation, and end-of-life management. Under the ecodesign framework, implementing measures can include **minimum energy performance standards** for IT equipment, and design that allows for repairability, upgradeability, and recycling of components.

Beyond individual products, the ecodesign approach is increasingly applied to the overall **architectural design and operation of data centres**. This broader perspective promotes design choices that optimise energy efficiency at the facility level, through modular design, efficient cooling and airflow management.

Nowadays, most sustainable IT institutes and non-governmental organisations agree that ecodesign of digital services should be part of an organisation's **broader strategy for sustainable IT**.<sup>73</sup> In particular, the **environmental footprint of digital services** must be evaluated through the prism of life cycle assessment, looking beyond direct energy consumption of the data centre facility and factoring in impacts associated with the various components, e.g., manufacturing of IT equipment (i.e., mining of critical raw materials, refining of metals), and their end-of-life processing.

The following frameworks provide guidance for integrating ecodesign principles into digital services:

- Institutes for Sustainable IT: **Handbook of Sustainable Design of Digital Services** (491),<sup>74</sup>
- French national reference framework for the ecodesign of digital services **RGESN**.<sup>75</sup>

### **FURTHER READING**

- N. Sundberg & R. Pastore (2026) [Sustainable IT Playbook for Technology Leaders](#)
- EcoDigIT (2024) [Life cycle assessment of digital services](#)
- Capgemini Research Institute (2021) [Sustainable IT – why it's time for a green revolution?](#)

<sup>71</sup> [ISO/IEC TS 20125-1:2026](#) Digital services ecodesign: Part 1: Ecopractices for life cycle stages, 27 February 2026.

<sup>72</sup> [Circular economy: definition, importance and benefits](#), European Parliament, 2023.

<sup>73</sup> [European Institutes for Sustainable IT \(ISIT Europe\)](#), [Sustainable Digital Infrastructure Alliance \(SIDA\)](#), [The Shift Project](#), [Alliance Green IT \(AGIT\)](#), [Boavizta](#), [Cigref](#), [ADEME](#), [GreenIT.fr](#), conference series [ICT for Sustainability \(ICT4S\)](#), etc.

<sup>74</sup> [Handbook of Sustainable Design of Digital Services](#), Institutes for Sustainable IT, 2021.

<sup>75</sup> [General Policy Framework for the Ecodesign of Digital Services \(original version in French\)](#), Arcep / Arcom, May 2024.

### 2.1.3. Energy performance of data centre facilities

As part of the European Green Deal framework, the Energy Performance of Buildings Directive (**EPBD**) is the EU's principal legislative framework for the decarbonisation of buildings and improving their energy performance.<sup>76</sup> Considering that the building sector accounts for approximately 40% of final energy use and around 36% of energy-related CO<sub>2</sub> emissions in the EU, the EPBD establishes a **new standard of 'zero-emission buildings'** for all new construction, and continues to promote the increasing use of renewable energy sources, all with a view to achieving climate neutrality by 2050.

As regards data centres, under this directive they must comply with **minimum energy performance standards** (MEPS) established for **non-residential buildings** that host their technical infrastructure and IT equipment. Although the EPBD does not impose direct efficiency thresholds for data centres, it encourages **energy-efficient design** and operation of data centres, including advanced cooling technologies, improved power management, and the increased use of renewable energy sources.

### 2.1.4. Renewable energy use

The revised Renewable Energy Directive (RED III) establishes the EU's legal framework for promoting the use of renewable energy across all sectors of the economy. As part of the European Green Deal policy framework and the Fit for 55 Package, the directive sets binding targets, introducing provisions relevant to large electricity consumers, such as data centres.<sup>77</sup>

Although the directive does not apply to data centres directly, it plays an important role in shaping the wider energy supply context in which data centres operate, thereby influencing **how data centres procure and use electricity**.

One key element is the promotion of **corporate renewable energy procurement**, including long-term power purchase agreements (PPA) between renewable energy producers and large-scale electricity consumers, enabling data centres operators to secure renewable electricity supply.

The directive also promotes **on-site generation of renewable energy**, encouraging the installation of renewable energy technologies such as harnessing solar energy via photovoltaic systems on buildings and associated infrastructure. In addition, the directive supports the development of local **renewable energy communities** and more flexible electricity markets, which can facilitate the integration of large electricity consumers such as data centres into local renewable energy systems. For more information about on-site generation of renewable energy, please refer to section 5.2. on page 71.

Another relevant aspect of RED III is its promotion of energy system integration through the recovery and **utilisation of waste heat** for integration into local district heating systems, offering another opportunity for integrating data centres into local energy systems. This can be done through the reuse of waste heat in district heating networks or nearby buildings. By promoting heat recovery, the directive seeks to improve the overall energy efficiency of urban energy systems and reduce the amount of energy that is dissipated as waste heat.

<sup>76</sup> [Directive \(EU\) 2024/1275](#) on the energy performance of buildings (**EPBD**), OJ L, 8 May 2024.

<sup>77</sup> [Directive \(EU\) 2023/2413](#) as regards the promotion of energy from renewable sources (**RED III**), 31 October 2023.

## 2.1.5. European best practice frameworks and voluntary guidelines

At the EU level, there are also several voluntary frameworks that promote best practices, green procurement standards and offer guidelines for data centres to improve their energy efficiency. The most widely recognised are listed in the table below and elaborated in the following sections.

**Table 10. European best practice frameworks for improving energy efficiency in data centres**

type of instrument	key provisions affecting data centres
<b>European Code of Conduct for Data Centre Energy Efficiency</b>	
voluntary initiative developed by the EU, providing guidance to European data centres to improve the energy efficiency of their operations, with a view to reducing overall energy consumption and promote sustainability	
<b>best practice reference document</b>	<ul style="list-style-type: none"> <li>outlines best practices for <b>improving data centre efficiency</b>, including management of IT equipment, cooling optimisation, airflow management, etc</li> <li>monitoring of KPIs, with <b>PUE</b> as key metric</li> </ul>
<b>EU Green Public Procurement Criteria for Data Centres, Server Rooms and Cloud Services</b>	
voluntary guidelines developed by the EU, to inform sustainable procurement of data centre equipment and services in the public sector, with a view to reducing life cycle impacts and improving energy efficiency	
<b>sector-specific guidance</b>	<ul style="list-style-type: none"> <li>recommends sustainability criteria such as <b>energy and resource efficiency</b>, , durability, and accounting for environmental impact across the entire lifecycle</li> </ul>
<b>Climate Neutral Data Centre Pact</b>	
voluntary pledge of data centre operators and trade associations to achieve climate neutrality by 2030	
<b>voluntary industry agreement</b>	<ul style="list-style-type: none"> <li><b>climate-neutral data centre operations by 2030</b></li> <li><b>PUE targets</b> for new facilities, <b>WUE</b> monitoring</li> <li>circular economy for IT equipment</li> </ul>

### 2.1.5.1. European Code of Conduct on Data Centre Energy Efficiency

The European Code of Conduct (CoC) for Data Centres is a voluntary initiative launched by the **Commission's Joint Research Centre (JRC)** in 2008 to raise awareness among data centre owners and operators about the importance of energy efficiency and facilitate informed decision-making to ensure cost-effective operation. The group accepts data centres of all sizes, and participants must undergo an energy audit and implement an action plan to improve their energy performance.<sup>78</sup>

Over the years it has developed into an authoritative industry platform that **publishes a compendium of best practice guidelines**, outlining a comprehensive list of improvement measures that provide a frame of reference for describing the state of practice.<sup>79</sup>

The best practice document is cited in Article 12 of Energy Efficiency Directive, and as of 2023, serves as a reference for the **Assessment Framework** under the Taxonomy Climate Delegated Act, turning the guidelines from recommendations to requirements subject to auditing.<sup>80</sup>

<sup>78</sup> [The EU Code of Conduct for Data Centres – towards more innovative, sustainable and secure data centre facilities](#), 2023.

<sup>79</sup> It is a 'living document' that is updated annually by industry experts to incorporate the latest technological developments. Most recent update: [2025 Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency](#), March 2025.

<sup>80</sup> [Assessment Framework for Data Centres in the Context of Activity 8.1 in the Taxonomy Climate Delegated Act](#), March 2023.

The code's best practices are organised into the following areas covering entire data centre lifecycle:

### 1. IT Equipment and Services

- **virtualisation and consolidation:** to maximise server utilisation, reduce number of physical servers
- **power management:** power-saving features in hardware/software, turning off components not in use
- **server selection:** choosing energy-efficient servers that are appropriately sized for the workload
- **storage optimisation:** using efficient solutions and data deduplication to reduce energy footprint

### 2. Facilities and Infrastructure

- **cooling and airflow management:** using strategies like hot/cold aisle containment, blanking panels, and variable-speed fans to improve cooling efficiency
- **cooling system design:** implementing advanced techniques, e.g. free or liquid cooling
- **power distribution and management:** optimising the power chain, from the utility connection to the server rack, to minimise energy loss. using highly efficient uninterruptible power supplies (UPS)
- **lighting:** replacing traditional lighting with energy-efficient LED systems and implementing motion sensors

### 3. Management and Operations

- **energy management system:** to measure, monitor, and improve performance, e.g., ISO 50001 EnMS
- **monitoring and reporting:** regular tracking of KPIs to identify areas of inefficiency
- **training and awareness:** educating staff on energy-efficient operational practices

#### 2.1.5.2. EU Green Public Procurement (GPP) Criteria for Data Centres, Server Rooms and Cloud Services

Published in 2020 under the JRC, the GPP Criteria Report provides another voluntary but actionable set of recommendations to help public authorities **integrate environmental performance requirements** into procurements related to data centres.<sup>81</sup> It targets new builds, renovations, equipment procurement, and cloud/outsourced services, offering technical specifications, selection and award criteria across 3 performance areas:

- **ICT system performance**, e.g., active efficiency, idle power, design for repair;
- **mechanical and electrical systems**, e.g., cooling optimisation, use of low-Global Warming Potential (GWP) refrigerants;
- **reduction of GHG emissions**, e.g., use of renewable energy, energy reuse factor.

Additionally, public tenders for procurement or renovation may integrate the following 4 criteria:

- **selection criteria:** to assess the capacity of economic operators to deliver sustainable solutions, e.g., prior experience in energy-efficient data centre projects or expertise in low-impact cooling systems;
- **technical specifications:** mandatory minimum requirements, e.g. connection to a district heating network and reuse of waste heat, to demonstrate feasibility or implementation;
- **award criteria:** used to compare and score offers, e.g. PUE target and score ranking;
- **contract performance clauses:** obligations during contract execution, e.g., mandatory monitoring and reporting of actual energy performance via KPIs and corrective action plans.

By guiding public procurement teams toward energy-efficient and low-emission infrastructure choices, these GPP criteria serve as a toolkit for **aligning digital infrastructure investments with EU climate and energy efficiency targets**. Despite being voluntary, these criteria also serve as a precursor to possible future regulatory frameworks, helping organisations prepare for increasing environmental requirements in the ICT sector.

<sup>81</sup> [EU Green Public Procurement \(GPP\) Criteria for Data Centres, Server Rooms and Cloud Services](#), European Commission, Joint Research Centre (JRC), 2020.

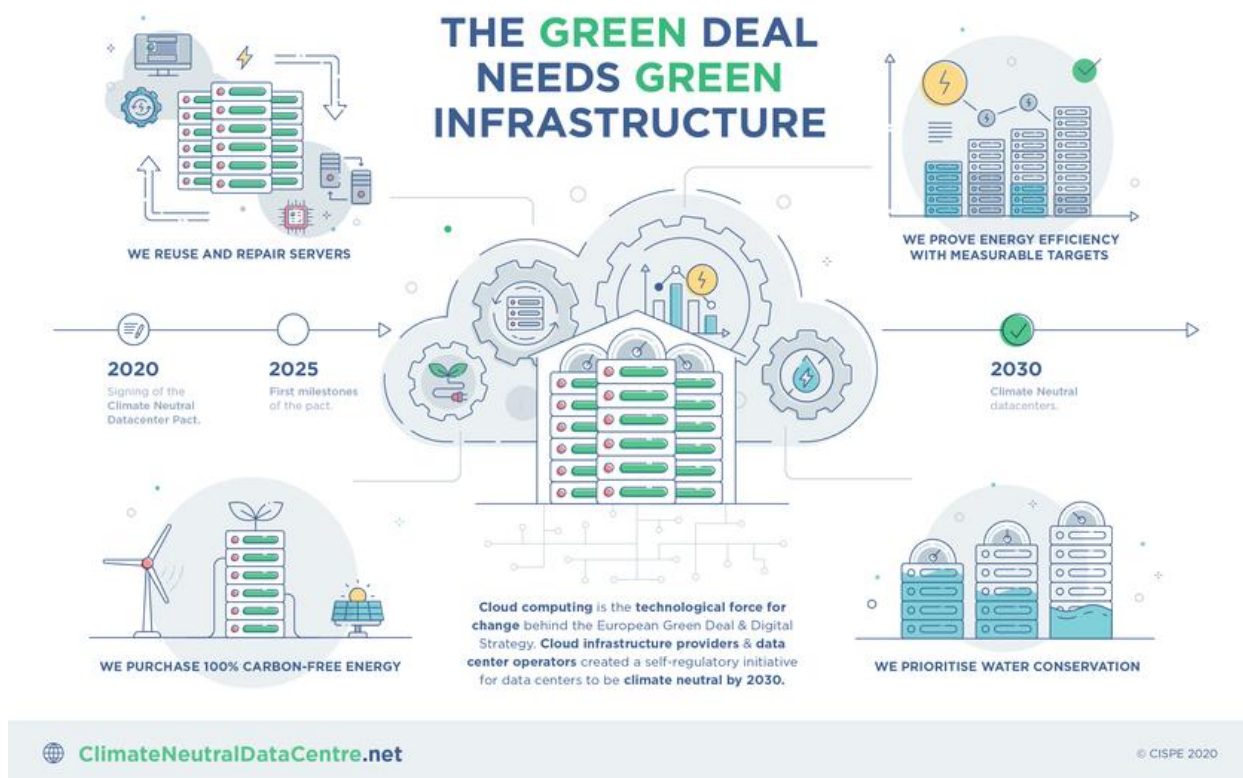
### 2.1.5.3. Climate Neutral Data Centre Pact

The Climate Neutral Data Centre Pact (CNDCP) is a voluntary initiative launched in 2021 by major cloud infrastructure providers and data centre operators in cooperation with the European Commission. The initiative aims to support the broader decarbonisation objectives of the European Green Deal by pledging that data centres operating in Europe will become **climate neutral by 2030**.<sup>82</sup>

To that end, the pact establishes measurable **sustainability targets** to be achieved between 2025 and 2030 in the areas of energy efficiency, renewable energy sourcing, water management, circular economy practices, and waste heat reuse:<sup>83</sup>

- **energy efficiency:** measured by power usage effectiveness (**PUE**), with new data centres operating at full capacity in cooler European climates are expected to achieve a PUE of 1.3 by 2025, while facilities in warmer climates have a target of 1.4, whereas existing data centres are required to meet these efficiency levels by 2030;
- **renewable energy:** signatories aim to match their electricity consumption with 75% renewable or carbon-free energy by 2025 and 100% by 2030, reflecting the growing importance of renewable electricity procurement for large digital infrastructure operators;
- **water usage:** measured by water usage effectiveness (**WUE**), data centre operators commit to monitoring and reducing water consumption and implementing efficient cooling technologies.
- **circular economy:** primarily in terms of utilising IT equipment to **reduce electronic waste**, e.g., increase the share of refurbished or repurposed components; reuse, repair, or recycle 100% of retired server equipment; .
- **circular energy systems:** particularly the **reuse of waste heat** generated by data centres, encouraging operators to integrate their facilities with district heating networks.

Figure 8. Climate Neutral Data Centre Pact pledges to become climate neutral by 2030



<sup>82</sup> For more information, please refer to the official website of [Climate Neutral Data Centre Pact](https://www.cispe.eu/Climate-Neutral-Data-Center-Pact).

<sup>83</sup> Climate Neutral Data Center Pact: [Initiative for Climate Neutral Data Centers in Europe](https://www.cispe.eu/Climate-Neutral-Data-Center-Pact).

## 2.2. INTERNATIONAL OUTLOOK

Although this report focuses primarily on European best practices and regulatory frameworks, national standards or regulatory instruments to reduce the environmental impacts associated with data centre operations have been introduced around the world, confirming the **growing global policy trend** towards more sustainable and energy-efficient IT infrastructure.

This section gives a brief overview of some voluntary guidelines at the global level, and then zooms into regulatory approaches implemented in the **United States, Japan and China**, which were selected due to the size and growth of their digital infrastructure and data centre markets, and the existence of national policies specifically targeting energy efficiency in data centres.

For a deeper analysis of international regulation, the interested reader may consult the report '**Policy Development on Energy Efficiency of Data Centres**', published under the International Energy Agency (IEA).<sup>84</sup> The report provides an international overview of policies, regulatory approaches, and measures such as performance standards, energy reporting schemes, data centre registries, and incentives for energy-efficient infrastructure. The report also examines policy instruments that could help reduce energy consumption in data centres, serving as a valuable resource for policymakers looking to design effective regulatory frameworks to manage the rapidly growing electricity demand associated with digital infrastructure, e.g., requirements for improved infrastructure efficiency, policies encouraging higher utilisation rates of computing equipment, and measures promoting more energy-efficient servers and IT hardware.

### 2.2.1. International best practice frameworks and voluntary guidelines

As in Europe, there are also several voluntary frameworks at the global level that promote best practices, green procurement standards and offer guidelines for data centres, such as:

**Table 11. International best practice frameworks for improving energy efficiency in data centres**

type of instrument	key provisions affecting data centres
<b>UN Sustainable Procurement Guidelines for Data Centres and Servers</b>	
United Nations guidance establishing technical specifications and performance indicators for procuring energy-efficient data centres equipment and servers	
procurement guidelines	<ul style="list-style-type: none"> <li>focus on <b>technical specifications</b> of IT equipment</li> <li>KPIs: <b>PUE, REF, WUE</b>, and <b>server efficiency</b> metrics</li> <li><b>renewable energy</b> use</li> <li>efficient <b>cooling</b> technologies</li> </ul>
<b>Science Based Targets initiative (SBTi)</b>	
voluntary corporate climate action organisation that develops standards, tools and guidance for setting science-based net-zero targets for reducing GHG emissions	
international corporate climate commitment framework	<ul style="list-style-type: none"> <li>provides methodology for science-based <b>greenhouse-gas reduction targets</b>;</li> <li>encourages companies to reduce <b>emissions across three scopes</b>, including emissions associated with data centre electricity consumption</li> </ul>

<sup>84</sup> *Policy development on energy efficiency of data centres*, International Energy Agency (IEA), Technology Collaboration Programme on Energy Efficient End-Use Equipment (**4E**), Efficient, Demand Flexible Networked Appliances (**EDNA**), 2024.

### 2.2.1.1. United Nations Procurement Guidelines for Data Centres and Servers

Published by the United Nations Environment Programme (UNEP) in 2025 to provide guidance for procuring energy-efficient and environmentally sustainable data centres and servers. By establishing technical specifications and performance indicators, this document enables the integration of sustainability criteria into purchasing processes, and infrastructure planning.<sup>85</sup>

The guidelines propose a set of **standardised sustainability metrics**, facilitating comparison of solutions based on energy performance and resource efficiency:

- power usage effectiveness (**PUE**) to measure overall energy efficiency of data centre facility,
- IT equipment energy efficiency for servers (**ITEEsv**) to measure hardware efficiency,
- water usage effectiveness (**WUE**) to evaluate water consumption related to cooling systems,
- cooling-related performance metrics such as the cooling effectiveness ratio (**CER**),
- renewable energy factor (**REF**) to assess the share of renewables in the energy mix.

The document also provides recommendations for improving data centre sustainability across several operational dimensions from energy-efficient servers and storage equipment, to optimising electrical distribution systems and deploying advanced cooling technologies.

### 2.2.1.2. Science Based Targets initiative (SBTi)

Established in 2015, the Science Based Targets initiative (SBTi) is a voluntary corporate climate action organisation that develops standards, tools and guidance for setting science-based net-zero targets for reducing GHG emissions.<sup>86</sup> Although SBTi focuses on **GHG emission targets**, the energy efficiency improvements in data centres serve as a mechanism to reduce emissions from electricity (*Scope 2*) or fuel (*Scope 1*).<sup>87</sup> For SBTi alignment these improvements must be:

- quantified in a manner that maps to emissions, i.e. emissions avoided;
- auditable and transparently reported, incl. baseline, scope, exclusions;
- indirect value chain emissions, sometimes also include embodied or supply chain elements.

In energy efficiency initiatives, science-based targets are characterised by the following features:

- **baseline and periodic reporting**: establish baseline year and start reporting metrics annually or more frequently; the baseline is critical for verifying progress against set targets;
- **PUE**: main metric; measured continuously (fleet-wide or per facility),
- **segregation of emission scopes**: direct emissions (*Scope 1*), indirect emissions (*Scope 2*), and emissions related to hardware and supply chain (*Scope 3*), especially for data centres which have large, embodied emissions in equipment and infrastructure;
- **renewable energy procurement / power purchase agreements (PPA)**: emissions reduction includes ensuring low carbon energy supply; mix of renewable energy and matching over time;
- **hardware and design**: upgrades in cooling design (free/liquid cooling, efficient chillers), server/hardware efficiency improvements (specialised chips), and operational improvements (e.g. server inlet temperatures, load balancing etc.), which all feed into PUE improvements;
- **third-party verification / standards / certifications**: independent audits, certifications (ENERGY STAR), public disclosure, e.g. sustainability reports or via Carbon Disclosure Project (CDP);<sup>88</sup>
- **continuous improvement and iteration**: systematic monitoring of metrics and tracking to identify inefficiencies (e.g. AI monitoring) to drive operational improvements, e.g. optimise cooling.

<sup>85</sup> *Sustainable Procurement Guidelines for Data Centres and Servers*, UN Environment Programme (*UNEP*), June 2025.

<sup>86</sup> For more, please visit [SBTi's official website](#).

<sup>87</sup> Categories defined by the *Greenhouse Gas Protocol*: *Scope 1* = direct emissions (fuel, generators), *Scope 2* = indirect emissions from purchased energy (electricity), *Scope 3* = other indirect emissions upstream/downstream of value chain.

<sup>88</sup> **CDP** (Carbon Disclosure Project) is a global non-profit that runs the world's only independent environmental disclosure system for managing their environmental impacts. For more, please visit [CDP's official website](#).

## 2.2.2. Regulatory framework in the United States of America

As of mid-2024, the U.S. has not introduced any nationwide, binding regulations with the same scope as other regions, increasingly relying on voluntary programmes, incentives, and recommendations.<sup>89</sup> The most recent initiatives regarding energy efficiency have been triggered by the surge in energy demand required for the development of AI.<sup>90</sup>

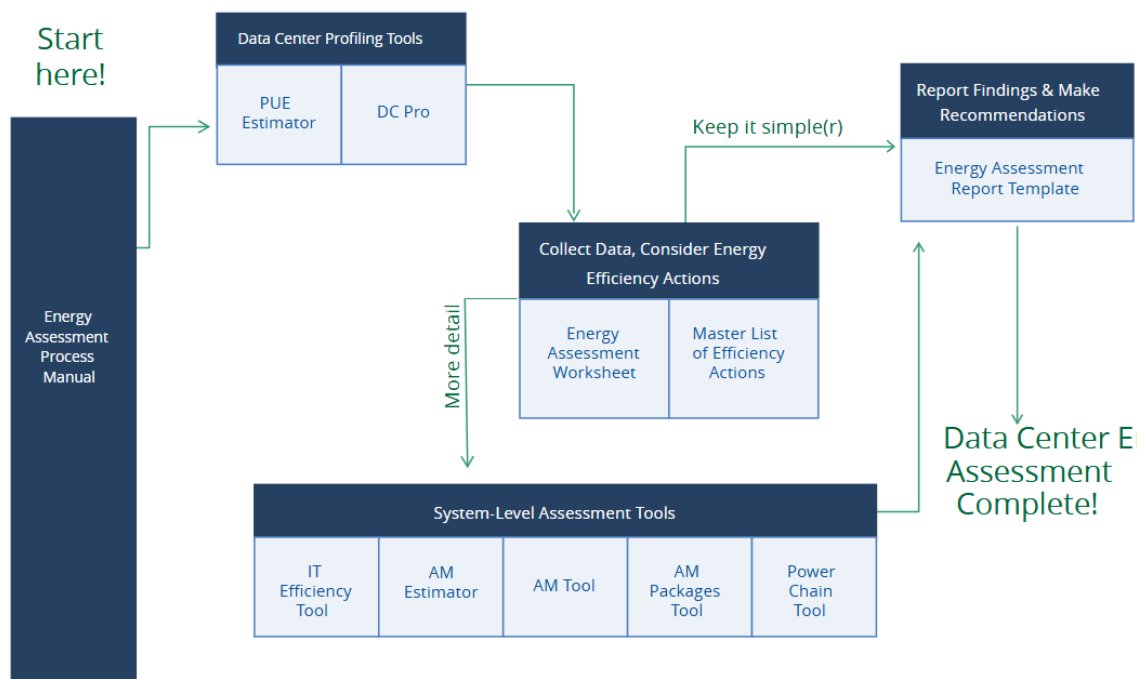
### Federal Initiatives

- **Federal Energy Act (2020)**: includes measures like establishing an open data initiative on energy use at federally owned data centres, creating a new metric for data centre energy efficiency, and developing a strategy for using energy-efficient IT equipment;<sup>91</sup>
- **Federal Data Centre Energy Practitioner training program**: delivered by the Center of Expertise for Data Center Energy at the Lawrence Berkeley National Laboratory, provides training for federal agencies for evaluating their data centres for energy efficiency;<sup>92</sup>

### Voluntary programmes and incentives

- **Federal Energy Management Program (FEMP)**: provides resources and guidance for improving data centre energy efficiency, in particular **Best Practices Guide for Energy-Efficient Data Center Design**<sup>93</sup> and **Data Center Energy Efficiency Toolkit**, offering a master list of efficiency actions, as well as guidance and tools for measuring and improving energy efficiency, e.g. energy assessment manual, worksheets, and templates;<sup>94</sup>
- **ENERGY STAR®**: energy-efficiency certification programme overseen by the Environmental Protection Agency (EPA) offers certification for data storage products;<sup>95</sup>
- **tax credits**: offered in some states for data centres meeting certain energy efficiency standards.<sup>96</sup>

Figure 9. Data Center Energy Efficiency Toolkit<sup>97</sup>



<sup>89</sup> [How Global Data Centre Regulations May Influence U.S. Policies](#), HWG LLP Energy Advisory, December 2024.

<sup>90</sup> [AI Data Centres Pose Regulatory Challenge. Jeopardizing Climate Goals – Study](#), DataCenter Knowledge, December 2024.

<sup>91</sup> U.S. Department of Energy, Departmental Sustainability background documents: [Energy Act of 2020](#).

<sup>92</sup> [Data Center Energy Practitioner training program](#), Center of Expertise for Data Center Energy, U.S. Department of Energy.

<sup>93</sup> [Best Practices Guide for Energy-Efficient Data Center Design](#), Federal Energy Management Program (FEMP) July 2024.

<sup>94</sup> [Energy Efficiency in Data Centres](#), Federal Energy Management Program (FEMP), U.S. Department of Energy (DOE).

<sup>95</sup> [ENERGY STAR® Expands Efforts to Improve Energy Efficiency of U.S. Data Centres](#), EPA press release, 16 August 2021.

<sup>96</sup> [Mitigating the Impact of Data Centres' Explosive Growth](#), Virginia Conservation Network, February 2024.

<sup>97</sup> [Data Center Energy Efficiency Toolkit](#), developed by [Center of Expertise \(CoE\) for Data Center Energy](#).

### 2.2.3. Regulatory framework in Japan

Japan's energy conservation policy is centred around the **Energy Conservation Act**, which plays a crucial role in achieving the country's climate and energy efficiency goals by imposing performance benchmarks, energy consumption thresholds, and reporting obligations.<sup>98</sup>

The act applies to data centres (designated as '*energy management factories*' in the commercial sector) with server rooms larger than 300 m<sup>2</sup>, covering nearly 79% of operators and 99% of total data centre energy consumption.<sup>99</sup>

For these facilities, the law introduces:

- **minimum energy performance standards (MEPS)**, based on a benchmarking system initially set at PUE ≤ 1.4 (corresponding to the top 15% most efficient facilities), a new benchmark must be proposed after more than 50% of the industry reaches this target;
- **reporting** of PUE and infrastructure characteristics for comparison.

The regulation also applies to '*specified business operators*', i.e. factories and workplaces consuming more than 6.749 MWh per year, therefore including large data centres. For these facilities, the law introduces:

- mandatory **annual energy reporting** by energy type and site,
- appointment of a **certified energy manager** within the organisation,
- submission of mid/long-term **energy efficiency plans** to authorities,
- requirement to **improve energy intensity** (= consumption volume / production volume) by an average of 1% per year over a 5-year period (energy use per unit of activity/output).

Together, these obligations combine **infrastructure-level performance standards with organisational energy governance mechanisms**. As such, the Japanese approach reinforces progressive improvement through a mix of benchmarking, self-regulated target adjustment, and internal accountability structures.

<sup>98</sup> [Introduction of the Energy Conservation Act in Japan](#), Energy Conservation Center Japan (ECCJ), 2023.

[Energy Efficiency and Conservation Policies in Japan](#), Institute of Energy Economics, Japan (IEEJ), 2024.

<sup>99</sup> As per data from [Japanese Ministry of Economy, Trade and Industry](#). For more, please refer to Japanese government's efforts on [climate change and decarbonisation](#).

## 2.2.4. Regulatory framework in China

To improve the energy-efficiency in its rapidly growing digital infrastructure sector, China has introduced one regulatory and one strategic instrument, which make up **a framework combining enforceable performance benchmarks with long-term planning targets**. However, take note that these examples do not represent a comprehensive overview of the regulatory framework for data centre energy efficiency in China.

### **Energy Efficiency Standard for Data Centres**

Effective since 1 November 2022, this mandatory national standard sets energy efficiency thresholds for newly-built, renovated and expanded data centres, including individual or modular units with independent power distribution, air cooling, and electric air-conditioning.<sup>100</sup> The standard defines three **energy-efficiency grades**, each with a corresponding PUE limit and technical specifications:

**Table 12. PUE-based data centre energy efficiency classification in China**

energy efficiency grade	PUE limit	applicable scenarios	energy saving requirements
Grade 1	≤1.20	newly-built high-performance data centres	adoption of advanced technologies, e.g. liquid cooling
Grade 2	≤1.30	general new projects	optimisation of air conditioning system and energy management controls
Grade 3 (limited value)	≤1.50	renovation and expansion projects	basic energy-saving renovation and cooling upgrades

### **Green Development Action Plan for Data Centres (2024)**

Released as part of China's broader digital sustainability programme, this non-binding strategic plan sets **mid-term energy performance targets** for the national data centre fleet, combining indicative goals with both mandatory and incentivised measures.<sup>101</sup>

by 2025	by 2030
<ul style="list-style-type: none"> <li>✓ achieve an <b>average PUE &lt;1.5</b> across the entire national fleet of data centres</li> <li>✓ increase the annual share of <b>renewable energy</b> usage in data centres by at least 10%</li> </ul>	<ul style="list-style-type: none"> <li>✓ reach internationally advanced standard levels in average <b>PUE</b>, as well as energy and carbon efficiency per unit of computing power</li> </ul>

To support these objectives, the plan outlines six key tasks to enhance data centre efficiency and sustainability:

- improving the **layout of data centre construction** to optimise performance;
- **geographical redistribution** and optimisation of data centre locations, e.g. promoting northern, naturally cooler regions;
- mandatory **retrofitting and upgrade** of outdated facilities through energy-saving and carbon-reduction measures;
- **strict adherence to energy and water efficiency requirements** for new projects;
- increasing the utilisation of **renewable energy sources**;
- promotion of **energy-efficient technologies and high-efficiency cooling systems**.<sup>102</sup>

<sup>100</sup> [Standard GB 40879-2021](#): Maximum allowable values of energy efficiency and energy efficiency grades for data centres, General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China.

<sup>101</sup> [China sets green targets for data centres](#), State Council of the People's Republic of China, press release, 24 July 2024.

<sup>102</sup> [China Launches Plan for Green Data Centers to Boost Sustainability](#), CEO Insights Asia, 08 August 2024.

# STATE OF PRACTICE



## 3. STATE OF PRACTICE

This chapter provides an overview of the state of practice in the field of data centre energy efficiency, starting with a **small-scale survey** conducted by Sopra Steria for the purposes of this report to build insights on the practical management of energy efficiency by European data centre operators.

In addition to the survey, state of practice is illustrated with select **examples from EU-funded projects**, highlighting the role of innovation and emerging trends in the areas of on-site generation of low-carbon energy, waste heat valorisation and energy efficient operation of digital infrastructure. The chapter concludes with a brief overview of innovations introduced by **hyperscalers**, highlighting the leading edge of innovation, while also illustrating pathways for technology transfer and scalability across the wider industry.

### 3.1. SURVEY ON DATA CENTRE ENERGY EFFICIENCY

- 3.1.1. Survey sample
- 3.1.2. Maturity model for energy efficiency
- 3.1.3. Survey questionnaire
- 3.1.4. Key Insights from the survey

### 3.2. INSIGHTS FROM EU-FUNDED PROJECTS

- 3.2.1. On-site generation of low-carbon electricity
- 3.2.2. Waste heat valorisation and thermal integration
- 3.2.3. Energy-efficient architecture and operations

### 3.3. INSIGHTS FROM HYPERSCALERS

## 3.1. SURVEY ON DATA CENTRE ENERGY EFFICIENCY

As part of this report, a small-scale survey was conducted by Sopra Steria among selected organisations in the EU, covering both data centre operators and users, to gather insights on their strategies and management of energy efficiency and sustainability in general. Although limited in scope, this perspective aims to provide complementary insights to the general state-of-practice.<sup>103</sup>

For further insights based on most recent data, we refer the reader to the large-scale survey with over 70 participants conducted by the **European Data Centre Association** (EUDCA) and reported in two successive documents from 2025 and 2026.<sup>104</sup>

### 3.1.1. Survey sample

The surveyed organisations were selected based on comparable characteristics to eu-LISA in one of several aspects, such as data centre size, preferably from public sector organisations, with facilities management and operations management responsibilities. From the seven organisations invited, five accepted to respond to the survey and disclose information about their energy efficiency situation, improvement initiatives and general sustainability initiatives.<sup>105</sup>

In general, the surveyed organisations are characterised as follows:

- 2 organisations are part of the EU ecosystem, and 1 is a large public sector organisation,
- 2 organisations are European private cloud providers, with some or limited managed IT services,
- 4 out of 5 organisations have recent or modernised data centre infrastructures,
- 3 out of 5 organisations have a strong level of activity on the facilities management,
- 3 out of 5 organisations have a strong level of activity on the operations management.

### 3.1.2. Maturity model for energy efficiency

The purpose of the survey was to gather informal, yet concrete, insights, and provide a **ranking against a maturity model** – a framework measuring an organisation’s maturity in a given area, and defined as the organisation’s ability to control its execution, manage incidents and errors, and improve the quality or use of its resources in a specific discipline or practice. The standard capability maturity model is illustrated in the figure below.

Figure 10. Standard capability maturity level



The maturity scaling used to rank surveyed responses is a simplified and aggregated model based on the standard Capability Maturity Model Integration (CMMI),<sup>106</sup> which was adapted to the energy efficiency subject of this study influenced by more advanced and documented models, in particular:

<sup>103</sup> The survey was conducted by Sopra Steria as part of the contracted work that forms the basis of this report, including part of the analysis and insights provided in the report.

<sup>104</sup> [State of European data centres 2025](#), and [State of European data centres 2026](#), European Data Centre Association (EUDCA).

<sup>105</sup> To encourage participation and allow for transparent information sharing, it was agreed that participating organisations would be covered by confidentiality and their names not disclosed; only type of organisation is indicated for operational context.

<sup>106</sup> [Capability Maturity Model Integration \(CMMI\)](#).

- CEN/CENLEC standard **CLC/TS 50600-5-1:2023** on the maturity model for energy management and environmental sustainability in data centres,<sup>107</sup>
- The Green Grid **Data Center Maturity Model (DCMM)**,<sup>108</sup>
- European Institutes for Sustainable IT (**ISIT**).<sup>109</sup>

**Table 13. Data centre energy efficiency maturity levels** <sup>110</sup>

	<b>description of energy efficiency maturity level ranking</b>
<b>0</b>	<ul style="list-style-type: none"> <li>▪ <b>nothing in place</b>, no energy efficiency or sustainability awareness</li> </ul>
<b>1</b>	<ul style="list-style-type: none"> <li>▪ energy efficiency or sustainability awareness as a requirement but no implementation</li> <li>▪ topic being <b>discussed for consideration</b></li> <li>▪ punctual initiatives taken to measure or control</li> </ul>
<b>2</b>	<ul style="list-style-type: none"> <li>▪ <b>minimal</b> best practices adoption</li> <li>▪ general strategy drafted</li> <li>▪ selective measurements, monitoring and reporting in place to compute and track key KPIs, typically PUE</li> </ul>
<b>3</b>	<ul style="list-style-type: none"> <li>▪ strategy outlined and communicated, with goals</li> <li>▪ operational <b>best practices</b> – power, lighting, cooling – partially or mostly in place</li> <li>▪ monitoring, control, reporting, improvement plans</li> <li>▪ internal audits and improvement plans are in place.</li> </ul>
<b>4</b>	<ul style="list-style-type: none"> <li>▪ <b>long-term strategies</b> in place, involving structural improvements in design, implementation, reuse or renewal</li> <li>▪ industry standards and best practices are followed</li> <li>▪ energy efficiency and sustainability are <b>organisational goals</b></li> <li>▪ external audits and reporting are done</li> </ul>

### 3.1.3. Survey questionnaire

The questionnaire was tailored for this study to offer an adequate balance between the breadth of covered topics, and depth, in terms of effort for participants. It is structured around **three key domains**, covering a total of 11 topics of 5 questions each, as outlined below.

<b>1. Operational, planning and strategic topics</b>
1. Practices for measuring, monitoring, controlling and optimising the energy footprint
2. Global energy strategy and IT
3. Energy supply sources and contracts
4. Operational, regulatory and other constraints
5. Energy purchasing policy and infrastructure renewal
6. Other related areas (5 questions)
<b>2. KPIs (implemented or planned)</b>
7. Common environmental footprint KPIs
8. Sustainability KPIs
9. KPIs integrating innovation, technology, automation and artificial intelligence
<b>3. Technical and operational characteristics</b>
10. Energy security level setup / reliability
11. Energy monitoring and characterisation

For the full questionnaire template, please refer to **Annex 1** on page 79.

<sup>107</sup> CEN/CENLEC standard CLC/TS 50600-5-1:2023 *IT - data centre facilities and infrastructures - Part 5-1: Maturity Model for Energy Management and Environmental Sustainability*.

<sup>108</sup> *Green Grid Data Center Maturity Model (DCMM)*. For more, please refer to *The Green Grid's DCMM Handbook*.

<sup>109</sup> *Guide to evaluating and influencing the maturity of stakeholders*, European Institutes for Sustainable IT (**ISIT**), 2024.

<sup>110</sup> *Maturity Model for Energy Efficiency in Mature Data Centres*, 2012, Curry E., Conway G., Donnellan B., Sheridan C. and Ellis K. in SMARTGREENS-2012: Proceedings of the 1st International Conference on Smart Grids and Green IT Systems.

### 3.1.4. Key Insights from the survey

The survey revealed both progress and disparity: while some organisations are leading the way by applying best practices and monitoring key metrics, others lag behind, especially in areas like tracking water usage and carbon impacts or embedding sustainability deeply in their management culture. Although continuous improvement programmes are in place, they differ in ambition and effectiveness. However, several organisations have demonstrated the **feasibility of significant efficiency gains** through targeted technical, organisational, and policy-driven measures, underpinned by investments in renewable energy, AI-driven optimisation, and ecodesign.

The organisations who **manage their own data centre facilities** have a much better understanding of data centre energy efficiency (i.e., power, cooling), and are more effective at driving related activities, i.e., monitoring, control, reporting, improvements, long-term investments.

The organisations who are **managing only IT operations** (i.e. users of data centre infrastructure):

- are minimally involved in energy efficiency considerations and are often unaware of their potential role as an IT organisation in reducing the environmental footprint, primarily because they see themselves as simply providing resources requested by the business, without much leeway to influence IT energy consumption beyond the choice of the IT equipment itself;
- rely on the data centre operator to meet their required security, resiliency and availability requirements, as reflected in the data centre tier classification level.

**All surveyed organisations track PUE** as a key KPI, most of them through the accurate use of measurement from the IT equipment (either globally or by rack/component) and often also power and cooling systems. The data is aggregated in a dedicated monitoring application, e.g., building management system, or energy management system.

Most of surveyed organisations conduct **annual energy efficiency and sustainability audits**, which provide very detailed information and recommendations, typically focusing on the reduction of energy costs, i.e., mainly the cost of chilling and environmental footprint (CO<sub>2</sub>).<sup>111</sup>

All organisations have **energy efficiency improvement programmes** in place, depending on the maturity and specific activity, with cloud providers clearly more advanced in this regard.

To sum up, when it comes to the impact of energy efficiency improvements:

- **smaller technical improvements**, such as mapping implementation and management categories, are often easier to implement but their benefits are often harder to isolate or measure. Although they usually deliver only modest PUE improvements in the short term, their cumulative effect creates a significant difference in a longer timeframe;
- more significant PUE impact is often achieved by **implementing technological changes**, involving equipment or technology replacement, e.g., replacing fan-based cooling by heat-exchange cooling.

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<sup>111</sup> In the context of data centres, '*chilling*' refers to a specific type of cooling where temperature is reduced to the range above freezing, usually below 8°C.

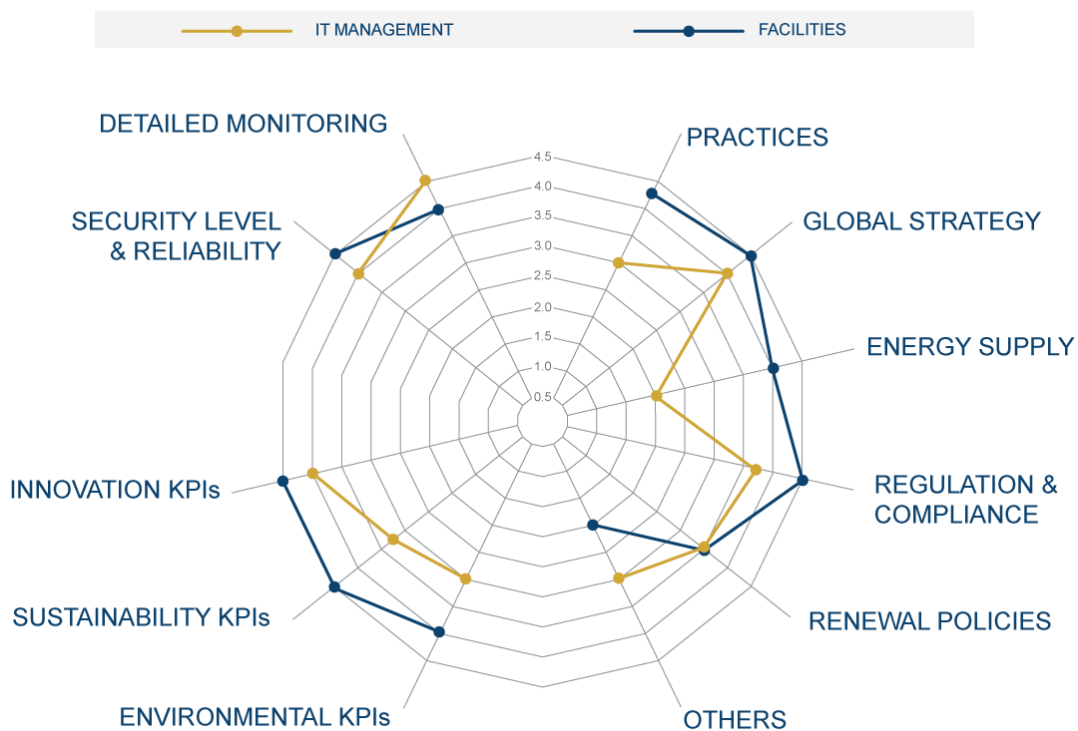
### Consolidation of maturity levels

The maturity levels associated with the responses from survey participants were consolidated based on the 11 topics and further averaged by the participant profile, i.e. facilities vs IT operations management, as reflected below in Table 14 and in Figure 11.

Table 14. Maturity levels of surveyed organisations, by role

domain	topic	facilities management	IT operations management
Operational, planning and strategic topics	practices	4,3	3
	global strategy	4,5	3,9
	energy supply	4	2
	regulation & compliance	4,5	3,8
	renewal policies	4,1	4
	other	2	3
KPIs (implemented or planned)	environmental KPIs	4	3
	sustainability KPIs	4,5	3,2
	innovation KPIs	4,4	3,9
Technical and operational characteristics	security level & reliability	4,5	4,1
	detailed monitoring	4,1	4,5

Figure 11. Spider chart of surveyed maturity levels



As depicted in the visualisation, the **management roles** (i.e., IT operations or facilities, or both) are a significant factor in the maturity level estimated based on their responses:

- **organisations that are managing their own data centre facilities score much higher** on the maturity level scale, especially on the various energy efficiency aspects covered;
- organisations having only IT operations management responsibility, or if their data centre facilities are managed by a separate service provider, show much lower maturity levels.

As highlighted in section 1.1.2. on page 14, about data centre energy consumption, the key factors for increasing maturity in the area of energy efficiency are close **collaboration**, **accountability**, and more active **involvement** of various roles across the energy consumption value chain.

## Overview of energy efficiency improvements

The surveyed organisations have implemented a wide range of energy efficiency improvements, which reflect not only their specific situation (available means), activity (platform provider and operator, or mainly user and consumer), but also the level of maturity.

In the case of **new data centres**, the ideal and most logical approach begins with defining an energy efficiency strategy. However, most situations involve **existing, already operational data centres** who usually start by implementing immediate, tangible improvements (*'quick wins'*), then progress to tactical enhancements in efficiency management, and conclude with more structural improvements integrated into an **energy efficiency strategy**.

The energy efficiency improvements can be grouped into the following three broad categories:

### 1. Energy efficiency STRATEGY

- align and comply with the **EU Code of Conduct for Data Centres** for energy efficiency
- internal engineering committees to improve performance at facility/infrastructure/operational levels
- **electricity purchasing strategies**: prefer renewable energies, multi-year bulk purchases
- deploy own production of renewable energy, e.g., solar panels
- **equipment purchasing strategies**: prioritise power efficiency, environmental impact and sustainability
- define equipment replacement for batteries, cooling, exchangers, UPS, with the latest generation equipment featuring highest efficiency
- experimental environments (e.g. sandbox data centre) to evaluate innovative technologies
- partner with research institutes<sup>112</sup>

### 2. Energy efficiency MANAGEMENT

- increase **computing density** especially in modern data centres with good efficiency
- **monitor** improvements through auditable performance metrics
- improve **monitoring data** analysis to spot behaviour patterns in the monitored metrics and implement preventive control of spotted patterns
- analyse and consolidate **workload** to fewer devices, reduce idle computing losses
- adopt **server efficiency rating tool** (SERT), in alignment with ISO/IEC 21836:2020 standard<sup>113</sup>
- extend the lifespan of **servers**, by:
  - ✓ buying refurbished/repairable servers or servers with flexible capacities (adding CPU or RAM)
  - ✓ reusing decommissioned servers
  - ✓ launching action plans to fight technical obsolescence: ecodesign of digital services or using open-source operating systems, with long-term maintenance and security support
- **decarbonisation plans** and target dates, incl. and set **net zero** greenhouse gas emissions targets
- use energy only from **renewable sources** (carbon footprint reduction)
- offer **training programmes** to increase awareness and impact at each stage of IT equipment lifecycle

### 3. Energy efficiency IMPLEMENTATION

- equipment redistribution for better heat dissipation
- improve ventilation or chilling with effective regulation
- set up containment corridors (hot/cold aisles)
- spot escaping hot air circulation and close gaps tightly
- deploy LED lighting, triggered by motion detectors
- relocating infrastructure from a low efficiency data centre to a highly efficient one, e.g., colocation scenario, or when closing an old data centre and opening a new one

<sup>112</sup> For example, French National Institute for Research in Digital Science and Technology (*Inria*) has partnered with cloud service provider *Qarnot Computing* to reduce its environmental footprint. [PULSE: a Challenge to reduce, control and valorize the environmental emissions of intensive computing](#), October 2022.

<sup>113</sup> [Server Efficiency Rating Tool \(SERT\)](#) global standard for measuring and evaluating the energy efficiency of servers, compliant with [ISO/IEC 21836:2020](#) server energy effectiveness metric (data centres), and [EU ecodesign requirements](#).

## 3.2. INSIGHTS FROM EU-FUNDED PROJECTS

At the EU level, improving data centre performance is addressed in the broader framework of the **EU's Digital Decade policy programme 2030**, laying down common objectives and targets for Europe's digital transformation.<sup>114</sup> In this context, data centres fall under the objective of **sustainable digital infrastructures**, which includes promoting research focused on measuring the impact of digital technologies, and developing sustainable, **energy and resource efficient innovations**.

This section provides overview of EU-funded projects, under the **Horizon Europe** programme, aimed at improving energy efficiency of data centres, in collaboration with municipalities, utilities and research institutes.<sup>115</sup> Together, they reflect the EU's strategic focus on reducing the environmental footprint of digital infrastructure and offer concrete examples of state-of-the-art practices.

This study covers 21 EU-funded projects on the basis of their relevance to data centre energy efficiency and sustainability to provide **validated technological solutions** backed by measurable outcomes. These initiatives demonstrate the feasibility and scalability of innovative solutions to reduce energy consumption, waste heat reuse, and integrate renewable power sources, offering a solid baseline for both policy development and industrial adoption.

A consolidated overview of these EU-funded projects is provided in the table below, whereas further details for each project, implementation timeline and budget, can be found in **Annex 2** on page 82.

**Table 15. Overview of EU-funded projects 2015-2027 under Horizon 2020 / Horizon Europe**

project category	number of projects	EU budget contribution	share of total contribution
cooling and thermal optimisation	8	50 million €	47%
interconnects and photonics for energy efficiency	5	24 million €	23%
efficient power supply and local energy systems	4	17 million €	16%
architecture and hardware optimisation	3	12 million €	11%
cloud / edge workload orchestration	1	3 million €	3%
<b>TOTAL</b>	<b>21</b>	<b>106 million €</b>	<b>100%</b>

In the context of data centre energy efficiency, this report highlights the following use cases:

- on-site generation of low-carbon power/electricity,
- waste heat valorisation and thermal integration,
- energy-efficient architecture and operations.

### 3.2.1. On-site generation of low-carbon electricity

This use case focuses on the decarbonisation of energy supply through on-site generation of low-carbon electricity to reduce reliance on fossil-based grid power while ensuring energy resilience.<sup>116</sup>

<b>E2P2</b> EcoEdge PrimePower	<i>Horizon 2020 project – 2021-2026 – hydrogen-powered data centres</i> – coordinated by RISE Research Institutes of Sweden
development of innovative on-site power generation solution for data centres using solid oxide fuel cells powered by hydrogen or biogas to provide a resilient energy source tailored to critical IT infrastructure	

<sup>114</sup> [EU Digital Decade policy programme 2030](#) promotes digital transformation, with a focus on **sustainable digital infrastructures**.

<sup>115</sup> [Horizon Europe: Digital](#) is a funding instrument of the EU Digital Decade policy programme. It focuses on the development of key digital technologies, supporting green and digital transformation, in alignment with the [European Green Deal](#).

<sup>116</sup> For more information, please visit [Eco Edge Prime Power](#), and coverage in Data Centre Dynamics (DCD) portal: [New EU clean hydrogen group funds €2.5m project for data center fuel cells](#), 14 December 2021.

### 3.2.2. Waste heat valorisation and thermal integration

Waste heat recovery projects aim to capture excess thermal energy generated during IT operations and facilities management by **redirecting it to local energy systems**, often district heating networks. These projects improve the ERF metric described in section 1.2.3. on page 25.

This approach improves energy efficiency of digital infrastructures and facilitates decarbonisation of **urban heating systems**, while reducing reliance on fossil fuels. The table below lists a select sample of projects that explore various approaches to the valorisation of residual heat from data centres.<sup>117</sup>

<b>ReUseHeat</b>	<i>Horizon 2020 project – 2017-2022 – urban heat reuse pilot – coordinated by IVL Swedish Environmental Research Institute, Sweden</i>
successful integration of excess heat from an air-cooled data centre into the low-temperature district heating network of the city of Brunswick in Germany via an external CO <sub>2</sub> heat pump	
<b>WeDistrict</b>	<i>Horizon 2020 project – 2019-2024 – 100% renewable district heating and cooling – coordinated by Ingeniera Especializada Obra Civil E Industrial SA, Spain</i>
fossil-fuel-free district heating and cooling solutions across four pilot sites in Spain, Romania, Poland and Sweden; integrated various renewable sources – biomass, geothermal, solar thermal, and waste heat from data centres – into local heating and cooling networks	
<b>Bytes2Heat</b>	<i>Horizon 2020 project – 2021-2024 – legal and market enablers – coordinated by DENEFF &amp; University of Stuttgart, Germany</i>
removing legal and commercial barriers to uptake of excess heat from data centres for heating applications; developing tools and guidelines for matching heat supply with demand and calculating ROI	
<b>MODERATOR</b>	<i>Horizon Europe project – 2024-2027 – thermal reuse via immersion cooling – coordinated by CERTH Centre for Research &amp; Technology HELLAS, Greece</i>
development of a novel, custom-designed immersion-cooling system using phase change materials (PCMs) to provide excess heat at 50-65°C	
<b>THUNDER</b>	<i>Horizon Europe project – 2024-2027 – seasonal heat storage – coordinated by RINA Consulting SPA (Registro Italiano Navale), Italy</i>
development of seasonal thermal storage based on thermochemical materials coupled with a high-temp. heat pump for accumulating excess heat (~60°C) in summer, for release into district heating network (86°C) in winter	

### 3.2.3. Energy-efficient architecture and operations

Improving energy efficiency through smarter design and operational practices is key to sustainable data centre operations. The following projects address cooling optimisation, workload management and infrastructure design to minimise energy use and reduce environmental impact.<sup>118</sup>

<b>BodenTypeDC</b>	<i>Horizon 2020 project – 2017-2020 – energy-efficient data centre prototype – coordinated by H1 Systems Mérnöki Szolgáltatások Kft., Hungary</i>
designed and operated a prototype facility in Boden, Sweden, to showcase sustainable data centre design with ultra-low energy use; exceptionally low PUE figures were achieved by using natural air and evaporative cooling (without refrigerants) and local low-carbon construction materials	
<b>HeatWise</b>	<i>Horizon Europe project – 2024-2026 – integrated thermal and workload management – coordinated by H1 Systems Mérnöki Szolgáltatások Kft., Hungary</i>
integrated thermal and energy optimisation in buildings with high IT-load; development of a hybrid dielectric liquid cooling system, digital twin for workload management, integrated building energy management system (BEMS), and a self-assessment tool to support energy strategy planning	

<sup>117</sup> For more information, please refer to dedicated project websites: [Bytes2Heat](#), [MODERATOR](#), [ReUseHeat](#), [THUNDER](#), [WeDistrict](#).

<sup>118</sup> For more information, please refer to dedicated project websites: [BodenTypeDC](#), [HeatWise](#).

### 3.3. INSIGHTS FROM HYPERSCALERS

When assessing the current state of practice in data centre energy efficiency, it is essential to consider the real-world examples from such hyperscalers as Google, Microsoft, or Amazon because these organisations operate at an unprecedented scale and technical sophistication. They manage some of the largest and most advanced data centre infrastructures around the world, giving them both the incentive and the capability to invest heavily in efficiency improvements. As a result, hyperscalers are often **early adopters and developers of cutting-edge technologies**, including custom hardware, AI-driven optimisation, advanced cooling systems, and renewable energy. Their solutions are typically validated in real operational environments and at scale, making them highly relevant **benchmarks for what is technically feasible** in modern data centre design and operation.

Furthermore, hyperscalers play a key role in **shaping industry standards and influencing best practices**, frequently pioneering and popularising efficiency techniques widely adopted across the sector, e.g., PUE targets, airflow management, workload optimisation. Their public disclosures, and engineering publications provide valuable insights into performance metrics, design strategies, and operational approaches that can inform both policymakers and other operators.

The figures provided in the table below should be taken with a critical view since they are self-reported by private enterprises, and not all have been independently verified. Nevertheless, they can provide a general sense of what can be achieved in data centre sustainability in the long term.

**Table 16. Data centre energy performance improvements reported by hyperscalers**

HYPERSCALER PROJECTS	TECHNOLOGY APPROACH	CLAIMED BENEFIT
<b>Google</b> <i>Cooling optimisation</i> <sup>119</sup>	AI-driven control (DeepMind) for real-time cooling management	<ul style="list-style-type: none"> <li>improved <b>PUE</b></li> <li>cooling energy reduction up to 40%</li> </ul>
<b>Microsoft</b> <i>Cooling and location</i> <sup>120</sup>	underwater data centres to maximise free cooling (Project Natick)	<ul style="list-style-type: none"> <li>reduced cooling energy demand</li> <li>improved reliability</li> </ul>
<b>Meta / facebook</b> <i>Facility design</i> <sup>121</sup>	Open Compute, airflow optimisation, evaporative cooling	<ul style="list-style-type: none"> <li><b>PUE</b> ~1.10 or lower</li> </ul>
<b>Amazon Web Services</b> <i>IT efficiency</i> <sup>122</sup>	custom processors (Graviton), high utilisation	<ul style="list-style-type: none"> <li>lower energy per workload</li> <li>metric: energy per compute unit</li> </ul>
<b>Equinix</b> <i>Energy reuse and sourcing</i> <sup>123</sup>	waste heat recovery, renewable procurement	<ul style="list-style-type: none"> <li>reduced carbon footprint (<b>REF</b>)</li> <li>heat reuse (<b>ERF</b>)</li> </ul>
<b>Switch</b> <i>Energy sourcing and infrastructure</i> <sup>124</sup>	100% renewable energy, efficient design	<ul style="list-style-type: none"> <li>near-zero operational emissions</li> <li>improved <b>PUE</b> and <b>REF</b></li> </ul>
<b>OVHcloud</b> <i>Cooling innovation</i> <sup>125</sup>	direct liquid (water) cooling	<ul style="list-style-type: none"> <li>reduced cooling energy demand</li> <li>improved <b>PUE</b> and cooling share</li> </ul>

<sup>119</sup> [DeepMind AI Reduces Google Data Centre Cooling Bill by 40%](#), Google DeepMind blog, 2016.

<sup>120</sup> [Microsoft finds underwater datacenters are reliable, practical and use energy sustainably](#), Microsoft, 2020.

<sup>121</sup> [Meta Data Center Sustainability](#).

<sup>122</sup> [Amazon Web Services \(AWS\) cloud](#).

<sup>123</sup> [Future First: Sustainability at Equinix](#).

<sup>124</sup> [Switch: Sustainable by Design](#).

<sup>125</sup> [Next-generation of AI-powered cooling to balance performance and environmental responsibility](#), OVHcloud, October 2025.

# *INNOVATIVE TECHNOLOGIES TO IMPROVE ENERGY EFFICIENCY*



# 4. INNOVATIVE TECHNOLOGIES TO IMPROVE ENERGY EFFICIENCY

The fourth chapter explores innovative technologies for improving data centre energy efficiency, from emerging infrastructure technologies to AI-based solutions for energy optimisation, in particular predictive maintenance, and smarter workload management that can reduce energy consumption while maintaining high levels of reliability and performance. Together, these technological developments illustrate how innovation can play a key role in improving data centre energy efficiency as demand for digital services continues to grow.

## 4.1. EMERGING INFRASTRUCTURE TECHNOLOGIES FOR ENERGY-EFFICIENT DATA CENTRES

- 4.1.1. Chiller fitted with a compressor using magnetic bearings
- 4.1.2. Lithium iron phosphate (LFP) batteries
- 4.1.3. Hydrogen storage
- 4.1.4. Fuel cells
- 4.1.5. High-voltage direct current (HVDC)

## 4.2. AI SOLUTIONS DRIVING ENERGY OPTIMISATION IN DATA CENTRES

- 4.2.1. Insights from the application of AI-based solutions for energy efficiency
- 4.2.2. AI-supported initiatives taken by hyperscalers

## 4.1. EMERGING INFRASTRUCTURE TECHNOLOGIES FOR ENERGY-EFFICIENT DATA CENTRES

In 2007, the EU launched the **Strategic Energy Technology (SET) Plan** to accelerate the development and deployment of low-carbon energy technologies.<sup>126</sup> It serves as the EU's main framework for coordinating research, innovation, and industrial policy in the energy sector, bringing together Member States, industry, research institutions, and the European Commission. The SET Plan serves as a collaboration framework for various **EU working groups on emerging technologies** that are showing great potential to data centre energy efficiency. This section will highlight the following:

- chiller fitted with a compressor using magnetics bearings,
- lithium iron phosphate (LFP) batteries,
- hydrogen storage,
- fuel cells,
- high voltage direct current (HVDC).

### 4.1.1. Chiller fitted with a compressor using magnetic bearings

In a data centre, the chillers are pumps that cool cold sources (e.g. rooms inside the data centre) and warm a hot source (e.g. outside air). Like any pump, they are equipped with a compressor that compresses a refrigerant gas, with cooling generated during its expansion phase.

**ADVANTAGES:** a compressor with magnetic bearings offers reduced friction compared to mechanical bearings, thus ensuring **higher energy efficiency**. This is a mature technology.

**DISADVANTAGES:** more expensive than mechanical bearings, use of rare earth minerals for permanent magnets; energy savings are achieved only when the compressor is active, not during free cooling phases. The payback time is long, if free cooling can be used most of the time.

#### RECOMMENDATIONS

Analyse the **payback time** of this solution. Consider that the energy efficiency gains are achieved by shifting environmental impacts from energy and GHG emissions to other types of impacts:

- **resource depletion** (abiotic mineral resources, non-renewable),
- **social impacts**, e.g. corruption and ethics considerations, respect for human rights. Note that magnetic bearings are made with **rare earth metals** (e.g., *lanthanides* in the Mendeleev's periodic classification), such as *neodymium*. Most of these materials come from China, where the Bayan Obo mine alone produces 45% of the world's rare earth materials. Rare earth materials are extracted in conditions that do not respect the health of miners and local populations, i.e. radioactivity, acidity, exposition to toxic gases such as SO<sub>2</sub>. According to the **EU's Critical Raw Material Report**, Europe is totally dependent on China for its sourcing of rare earth minerals.<sup>127</sup>

Obtain commitments from manufacturers on effective recycling rates, supply chain sustainability, and traceability back to mines, in line with the **European Critical Raw Materials Act**.<sup>128</sup>

<sup>126</sup> [SET Plan](#): main framework for coordinating research, innovation, and industrial policy in the EU's energy sector, bringing together Member States, industry, research institutions, and the European Commission.

<sup>127</sup> For more, please refer to European Commission's dedicated page on the [Critical Raw Materials Act](#).

<sup>128</sup> [Regulation \(EU\) 2024/1252](#) identifies 34 critical raw materials (CRM) based on their economic importance and supply risk, including 17 strategic raw materials (SRMs) crucial for green and digital transitions.

#### 4.1.2. Lithium iron phosphate (LFP) batteries

In general, batteries are used in data centres for **backup power to ensure power continuity** in the event of losing electrical supply from the external power supply network. In such cases, the system **switches automatically** to diesel generators, which requires time to **synchronise** with the generators. During this time an uninterruptible power supply (**UPS**) ensures a steady power supply by using large battery parks. The most commonly used technology is lead-acid batteries, but increasingly, more innovative lithium iron phosphate (LFP) batteries are suggested as a replacement, offering higher reliability, longer lifespan, and lower maintenance needs. When using LFP batteries, it is important to ensure **sustainable supply chains** (especially for metals and minerals), coupled with **effective recycling**, and specific action plans should be requested from suppliers to monitor their activity and improvements.

##### ADVANTAGES:

- very mature technology with higher reliability and lifespan compared to lead batteries
- no risk of thermal runaway, unlike other lithium-ion technologies, e.g., LNMC (*lithium nickel manganese cobalt*)
- no memory effect, low self-discharge
- reduced maintenance tests and costs

##### DISADVANTAGES:

- more expensive than lead batteries, but less expensive than LNMC
- European recycling process not fully optimised but the **EU Battery Regulation** (2023) has introduced improvements in terms of sustainability<sup>129</sup>
- since LFP batteries contain less expensive metals, their recycling will also be less profitable

#### RECOMMENDATIONS

Obtain commitments from...

##### MANUFACTURERS on:

- recycling rates, supply chain sustainability, and traceability back to mines, in line with the EU Battery Regulation and Critical Raw Materials Act
- request digital product passports<sup>130</sup>
- life cycle assessment comparing LFP with conventional lead batteries, consider payback-time, incl. maintenance
- recycling process to avoid uncontrolled outsourcing and creation of unregulated landfill sites in poor countries

##### RESPONSIBLE ENTITY on the traceability process of non-recyclable parts:

- destruction,
- landfill
- or burial.

#### Initiatives at EU level

Under the SET Plan, the **Working Group on Batteries** offers a collaborative platform to support the development of competitive, sustainable battery technologies that contribute to Europe's energy transition and industrial autonomy. The group brings together experts from EU Member States, industry, research organisations, and academia to coordinate research, innovation, and industrial development across the battery value chain in the EU.<sup>131</sup> Its activities are closely linked to initiatives such as **Batteries Europe**, **European Battery Alliance**, and **BATT4EU partnership**, which collectively aim to strengthen the European battery ecosystem and guide priorities for battery research, manufacturing, recycling, and deployment.<sup>132</sup>

<sup>129</sup> [Regulation \(EU\) 2023/1542](#) concerning batteries and waste batteries (**EU Battery Regulation**), OJ L 191, 28 July 2023.

<sup>130</sup> **digital passport**: detailed information accessible via QR code to help consumers make informed decisions when purchasing batteries, especially useful for professionals along the value chain. For more, please refer to [Commission's dedicated website](#).

<sup>131</sup> SET Plan Implementation [Working Group on Batteries](#).

<sup>132</sup> For more, please refer to dedicated websites: [Batteries Europe](#), [European Battery Alliance](#), and [BATT4EU partnership](#).

### 4.1.3. Hydrogen storage

The use of dihydrogen (H<sub>2</sub>) as an energy vector may appear as an attractive alternative for producing part of the energy consumed by a data centre. If renewable energy production exceeds data centre needs, an **electrical hydrolyser can produce H<sub>2</sub> for storage**, i.e., to be used at a later time to compensate for shortfalls when demand exceeds supply. H<sub>2</sub> production and storage may become a cornerstone for the future of ‘smart energy grids’ or ‘smart buildings’.

With this in mind, it is essential to use either H<sub>2</sub> produced from:

- **decarbonised/renewable electricity** by electrolysis of water, or
- **biomass**.

Otherwise, the **carbon balance** of using H<sub>2</sub> produced from conventional processes is likely to be worse than that of burning fuel. In 2023, 99% of H<sub>2</sub> was produced from CH<sub>4</sub> using steam methane reforming (SMR) or from gasification of coal. Green H<sub>2</sub> is significantly more expensive than grey hydrogen, typically 50% to 100% higher in cost.

In addition, it is very **expensive to store and distribute** H<sub>2</sub> over the long term, since it requires stringent safety precautions. For example, to prevent the very small molecules of H<sub>2</sub> from permeating metal storage containers and weakening their mechanical integrity, space technologies use titanium liners inside the tanks. Consequently, insurance companies may be reluctant to support the use and storage of H<sub>2</sub>. However, as the development and standardisation of H<sub>2</sub> storage evolves in line with emerging standards and safety measures, insurance companies may be more open to this solution.

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**ADVANTAGES:** when used with fuel cells (*see next section*) it can **replace diesel generators** that are not always reliable and require the storage of large quantities of fuel, carrying risks of fire, pollution, and bacterial growth that can degrade the fuel and cause generator failures. It can be a **solution to store** renewable electricity and increase both self-consumption and self-production capacities

**DISADVANTAGES:** costs, risks associated with H<sub>2</sub> storage

#### RECOMMENDATIONS

Some fuel cells can use H<sub>2</sub> but also methane (CH<sub>4</sub>). CH<sub>4</sub> networks already exist in cities, technologies for storage and distribution are standardised and reliable, they do not require large installations.

#### **Initiatives at EU level**

The **Temporary Working Group on Hydrogen (TWG H<sub>2</sub>)** was established under the SET Plan in 2023 to strengthen the coordination of hydrogen-related research and innovation activities across Europe. The working group focuses on **advancing hydrogen technologies across the entire value chain**, from production and transport to storage and end-use, while also addressing cross-cutting issues such as sustainability, regulatory frameworks, and skills development. Its main objective is to implement the Strategic Research and Innovation Agenda (**SRIA**) developed through the European Research Area pilot initiative on **green hydrogen**,<sup>133</sup> while fostering collaboration among EU Member States, industry, and research organisations. Through coordinated research programmes and cooperation between national and EU initiatives, TWG aims to accelerate the deployment of hydrogen technologies and enhance Europe’s competitiveness in the emerging global hydrogen economy.<sup>134</sup>

<sup>133</sup> [Strategic Research and Innovation Agenda 2021-2027](#) of the Clean Hydrogen Joint Undertaking, 2022

<sup>134</sup> SET Plan Implementation [Temporary Working Group on Hydrogen \(TWG H<sub>2</sub>\)](#).

#### 4.1.4. Fuel cells

Fuel cells offer a **lower-carbon alternative to conventional diesel generators**, serving both backup and even primary power needs. When powered by methane (CH<sub>4</sub>) or hydrogen (H<sub>2</sub>) – ideally sourced from renewable or low-carbon pathways – they can significantly reduce emissions while maintaining a reliable energy supply.

While promising in terms of emissions and noise, hydrogen fuel cells remain expensive and technically challenging at scale. It should be noted that as their response time is not fast enough to meet electricity demand variations, batteries must be used in a hybrid mode. Therefore, H<sub>2</sub> or CH<sub>4</sub> fuel cells cannot replace stored batteries but may reduce their required capacity, compared to UPS.

**ADVANTAGES:** higher reliability, longer lifespan and much lower noise, compared to diesel generators.

**DISADVANTAGES:**

- storage risks, if H<sub>2</sub> is used
- very expensive compared to diesel generators, currently it is unrealistic to expect any payback time
- pioneering projects are being tested (e.g.), but with limited scope (i.e., Google in only small part of data centre),<sup>135</sup> mainly as technical demonstrators for applied research and communication purposes
- the technology is not expected to be deployed on a large scale in the near term.
- fuel cells also contribute to the depletion of abiotic, non-renewable mineral resources, as they use rare and expensive metals, e.g. platinum

#### RECOMMENDATIONS

The use of CH<sub>4</sub> fuel cells, through the existing gas network, appears more feasible than using H<sub>2</sub> storage, even if its use produces CO<sub>2</sub>. Given the **relatively high cost** of implementing fuel cells as an alternative to diesel generators, such projects may be most appropriately positioned as long-term strategic sustainability initiatives, supported by a thorough cost-benefit analysis.

#### *Initiatives at EU level*

As part of the effort to further develop this innovative technology, the EU has recently funded the **Eco Edge Prime Power (E2P2) project**, which developed and demonstrated low environmental impact fuel cells that provide economic and resilient prime power solutions for data centres in populated areas. The project envisioned revolutionising the power distribution to urban and edge of the network data centres by bringing **European fuel cell technologies** to market within an open standard that will enable their simultaneous deployment within a modular and extensible ecosystem, while also ensuring compatibility with readily available data centre products and services.<sup>136</sup>

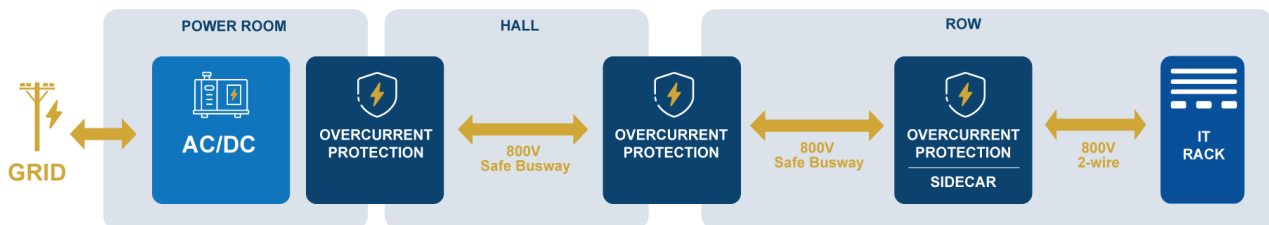
<sup>135</sup> [Hydrogen Fuel Cells in Data Centers: A Clean Energy Revolution](#), Plug Power blog, August 2024.

<sup>136</sup> For more information, please visit [Eco Edge Prime Power](#), and coverage in Data Centre Dynamics (DCD) portal: [New EU clean hydrogen group funds €2.5m project for data center fuel cells](#), 14 December 2021.

#### 4.1.5. High-voltage direct current (HVDC)

The current power distribution standard in data centres is 230/400V AC (alternating current) to the rack. Each server is equipped with an internal power supply, converting the 230V AC to 12V DC, 5V DC, and lower voltages required within the server. The promotion of a standard DC (direct current) distribution within computer racks, first at 12V, later at 48V (54V) is now evolving towards 800V high-voltage DC (HVDC). The figure below depicts the implementation of HVDC technical architecture.

Figure 12. Nvidia 800V HVDC architecture for minimised energy conversion losses<sup>137</sup>



**ADVANTAGES:** HVDC distribution offers several key advantages for data centres:

- **improved energy efficiency:** HVDC systems can achieve greater energy efficiency regardless of data centre load. While modern AC server power supplies have improved significantly, DC power supplies are still more efficient. This is because DC systems **eliminate the need for AC-to-DC conversion** within the server, which is a major source of energy loss;
- **reduced complexity and redundancy:** HVDC **simplifies the power delivery infrastructure**. In a traditional AC system, power is converted from AC to DC for the UPS battery and then converted back to AC before being distributed. With a DC distribution system, this double conversion is eliminated, as the power can be delivered directly from the UPS to the servers in DC format. This reduces the number of components and, consequently, the points of potential failure;
- **support for high-density racks:** as server racks become denser, particularly with the demands of AI data centres and powerful graphics processing units (GPUs) (e.g. Nvidia), conventional 230V AC systems may become impractical or even impossible to use due to power limitations and thermal management challenges. The **emerging 800V HVDC standard** is designed to meet these high-density requirements, enabling the deployment of more powerful computing equipment with a smaller footprint. This trend suggests that HVDC systems will become a **standard feature of next-generation high-performance data centres**.

**DISADVANTAGES:** The current *de facto* standard is 230/400V AC and therefore, its supply chains and vendor options are currently far more mature and established compared to DC power systems. There is likely to be a significant delay before the widespread adoption of a new standard around 800V HVDC.

### RECOMMENDATIONS

The choice of a power distribution system is directly dependent upon the planned rack power densities:

- **up to approx. 20kW:** conventional 230V AC power distribution remains a viable and reliable solution; while HVDC systems can offer marginal energy efficiency gains, implementation is not essential;
- **20kW to 50kW range:** no definitive standard solution; transitional zone where the choice between advanced AC and DC systems depends heavily on specific goals, e.g. desired efficiency, existing infrastructure, and budget. In this range, the limitations of the traditional 230V AC power distribution standard become more apparent, leading operators to seriously evaluate trade-off between the familiarity of AC and the emerging benefits of DC, *for more, see Table 17 on the following page*;
- **at 50kW and above:** HVDC systems become a much more compelling option. For these high-density environments, a rigorous evaluation of HVDC is strongly recommended due to its superior efficiency, reduced complexity, and ability to meet the demanding power requirements of modern hardware.

<sup>137</sup> [Nvidia 800 VDC Architecture Will Power the Next Generation of AI Factories](#), Nvidia blog post, 20 May 2025.

In the 20 to 50 kW range, approaches implemented by Schneider Electric,<sup>138</sup> Veriv,<sup>139</sup> and the Open Compute Project (OCP)<sup>140</sup> are summarised in the table below:

**Table 17. Advantages and disadvantages of power distribution types in the 20 to 50kW range**

power distribution type	advantages	disadvantages
<b>high-efficiency three-phase AC (400V/230V)</b>		
<p>Default and most common approach, directly delivered to the rack. Higher levels achieved more efficiently than with single-phase AC.</p> <p>Represents an incremental, well-understood improvement over older designs;</p> <p>viable solution for densities up to and around 30kW.</p>	<p>Utilises existing technology/expertise, wide availability of equipment, lower initial capital expenditure.</p>	<p>Higher current leads to thicker, more expensive copper cables.</p> <p>Efficiency losses from multiple AC/DC conversions more significant than at lower densities.</p>
<b>800V high-voltage DC (HVDC)</b>		
<p>HVDC becomes increasingly attractive in the above 20kW range, as efficiency gains and reduction in cable size and cost start to provide a clear return on investment, especially for new builds or major renovations where the infrastructure can be designed from the ground up.</p>	<p>Superior energy efficiency (fewer conversion steps), thinner and cheaper cabling, and simplified distribution.</p>	<p>Higher initial cost for DC-specific components, less industry familiarity compared to AC systems.</p>
<b>48V DC (as used in OCP Open Rack)</b>		
<p>Popularised by the Open Compute Project (OCP), this architecture brings a 48V DC busbar directly to the servers in the rack, eliminating individual AC/DC power supply units in each server in favour of a centralised rack-level power shelf; highly efficient for server-level power delivery.</p>	<p>Very high efficiency inside the rack, simplified server design (no PSUs), promotes standardisation and serviceability.</p>	<p>Suited for new builds designed around OCP standards; not practical for retrofitting traditional data centres.</p> <p>Planning for power must be done in lockstep with IT hardware selection.</p>

### **Initiatives at EU level**

Given the important role that DC and HVDC and technologies play in **integrating renewable energy sources** in the EU energy system, and the potential impact that they can bring in terms of energy efficiency, a **Working Group on Direct Current Technologies** has been established at EU level.<sup>141</sup> It brings together national representatives from Member States and stakeholders from the energy sector, to support this **key technology for energy transition** by aligning ongoing research, development and innovation across Europe, and developing new joint initiatives. The working group has set two implementing plans, one for the development and integration of high-voltage direct current (HVDC), and another focusing on low-voltage direct current (LVDC) technologies.<sup>142</sup>

<sup>138</sup> [Quantitative Comparison of High-Efficiency AC vs. DC Power Distribution in Data Centers](#), Schneider Electric, 2015.

<sup>139</sup> [Wired for change: Data centers' dynamic shift to hybrid power solutions](#), Vertiv white paper, 2024.

<sup>140</sup> Open Compute Project (OCP): [Open Rack v2.1 Standard Compliant 48V design](#) (2018) and [Open Rack Specifications](#).

<sup>141</sup> For more information, please refer to [EU Working Group on Direct Current Technologies](#).

<sup>142</sup> For more, please refer to implementation plans for [HVDC systems and DC technologies](#) (2021) and [LVDC systems](#) (2024).

## 4.2. AI SOLUTIONS DRIVING ENERGY OPTIMISATION IN DATA CENTRES

As data centres continue to grow in scale and complexity, artificial intelligence (AI) is emerging as a **transformative force for optimising operations**, particularly in improving energy efficiency. For example, Google applied DeepMind's reinforcement learning techniques to optimise data centre cooling systems, reportedly reducing cooling-related energy consumption by 40%.<sup>143</sup>

Although AI is being increasingly used in data centres, a key finding from research, expertise and experience is that in most cases **AI-based solutions are not mature enough** to be considered as a first line fix for optimising data centre energy efficiency and are yet to demonstrate tangible energy efficiency gains that go beyond the results achieved through more conventional control and optimisation methods that still offer predictable, cost-effective gains.

The research perspective is cautiously optimistic about AI's future potential, while the operational experience is more sceptical and instead recommends a **'frugal AI' approach**, which stresses the importance of **focusing on real needs first** and choosing the most suitable technology based on those insights.<sup>144</sup>

### 4.2.1. Insights from the application of AI-based solutions for energy efficiency

In data centres, AI is primarily used to deliver **real-time operational intelligence** that can be used to **improve infrastructure efficiency** by adjusting energy consumption while maintaining performance and reliability.<sup>145</sup> By monitoring such parameters as temperature, power consumption, airflow, server utilisation, and cooling system performance, AI algorithms can analyse large streams of operational data from sensors, IT equipment, and facility management systems. This enables smarter, more sustainable infrastructure management through AI-driven smart metering, alerting and control. Furthermore, machine learning models can **identify patterns and anomalies** in operational data, providing managers valuable input for optimising workloads, adjusting cooling and power distribution.

In large-scale cloud and hyperscale facilities, **AI-driven control systems** can continuously optimise infrastructure operation, improving key efficiency metrics such as PUE, and enabling more sustainable management of computing resources in real time.<sup>146</sup> The integration of AI with business process management (BPM) and robotic process automation (RPA) software is driving the rise of **intelligent automation** – systems that not only predict and optimise but also act autonomously. According to IBM, 80% of executives across different industries plan to automate IT networking, and 76% plan to automate the management of IT operations.<sup>147</sup>

In this context, it is important to bear in mind that although AI has the potential to become a very **powerful tool in data centre energy management**, it is still imperative that before introducing machine learning solutions, data centre owners and operators should:

- ensure the quality of operational data,
- implement standardised metering and monitoring,
- maintain existing energy-saving systems and functions.

<sup>143</sup> [DeepMind AI Reduces Google Data Centre Cooling Bill by 40%](#), Google DeepMind blog post, July 2016.

<sup>144</sup> [General framework for frugal AI](#), AFNOR, 2024.

<sup>145</sup> [AI for energy optimisation and innovation](#), International Energy Agency (IEA), 2025.

<sup>146</sup> [Optimising IT infrastructure and operations with AI](#), and [Intelligent Automation](#), IBM, 2023.

<sup>147</sup> [The power of AI & Automation: Proactive IT](#), IBM, 2023

Beyond infrastructure-level optimisation, AI is also playing an increasing role in **capacity planning** and **predictive maintenance**. For example, predictive models can support workload forecasting that enables more efficient allocation of computing resources, or detect faults before they affect operations and identify root causes of system anomalies.

For such applications, it is increasingly important to ensure **human-in-the-loop** approaches, where AI models act as an interface between complex analytics engines and human operators, **translating insights from operational data into actionable recommendations**. For example, an AI model can summarise a predictive maintenance alert, suggest procurement actions based on capacity forecasts, or generate draft compliance reports from sustainability data. This hybrid approach enhances decision-making while **maintaining human oversight and accountability**.

In conclusion, early research shows that AI can deliver **promising results in specific contexts**, but those results are often hard to scale. Considering that conventional control and optimisation methods still offer cost-effective gains, AI should only be considered after the essential monitoring, data quality and operational issues have been addressed, and only if there is a clear business case.

In the near term, the most realistic and valuable uses of AI are in **operations, monitoring, and forecasting**, e.g., data-quality automation, AI-driven smart metering, workload forecasting, dynamic adjustment of cooling and power systems, anomaly detection and predictive maintenance. These use cases are low-risk, high-return because they amplify the value of existing telemetry and reduce downtime and waste without taking control away from humans.

## RECOMMENDATIONS

Before any AI initiative is pursued to improve data centre energy efficiency, the following actions should be addressed in first order:

- **accurate electrical schematics:** maintain up-to-date electrical diagrams for the entire facility and IT equipment, from supply point to consuming equipment, ensuring that meters are placed correctly and measurements are interpretable;
- **comprehensive metering:** cover all energy usage needed for calculating relevant KPIs, in particular PUE, in compliance with ISO standard 30134, i.e., from IT equipment (servers, network) and also facilities, incl. high-voltage transformers and distribution panels;
- **unified data monitoring:** integrate energy consumption data from IT and facilities into a single database, record data at electrical distribution panels and store in building management system;
- **data retention and sampling:** store electricity consumption data for at least two years to allow meaningful comparisons, with a sampling frequency of every 15 minutes to one hour;
- **maintain existing energy-saving functions:** make sure that built-in energy-saving features such as free cooling, and containment are implemented and effectively operated;
- **prioritise simple, low-impact solutions:** do a mapping of actual needs and begin by trying simpler, less energy-intensive solutions before escalating to AI.

It is recommended to start with applications where AI solutions amplify existing value and then expand progressively into higher-autonomy, higher-value domains once the foundational data, governance and validation layers are in place.

- **AI quick wins:** deploy current mature and tested AI tools for anomaly detection, forecasting, and predictive maintenance;
- **AI pilot projects** can be run to test assistive control and scheduling optimisers in non-critical zones using a digital twin for validation;
- **AI-driven** automated control and portfolio-level optimisation should be implemented only after safety, explainability and net-environmental-benefit have been proven.

## 4.2.2. AI-supported initiatives taken by hyperscalers

Considering that hyperscalers are trendsetters in the development of resource efficient large-scale data centres, this section provides some examples of reported hyperscaler initiatives identified via desktop research. Please note that these are not exhaustive nor confirmed by respective companies.

Table 18. AI-supported initiatives by hyperscalers

HYPERSCALER PROJECTS	AI ACTION	CLAIMED BENEFIT
<b>Google → DeepMind</b> <i>Smart cooling control (HVAC)</i> <sup>148</sup>	DeepMind has deployed an AI for real-time adjustment of system settings for HVAC (heating, ventilation, and air conditioning), e.g., air flow temperature, fan speed, etc.	<ul style="list-style-type: none"> <li>40% reduction of cooling energy</li> <li>PUE improvement <b>-15%</b> (record PUE ≈ 1,10 in 2019)</li> </ul>
<b>Microsoft → Azure AI</b> <i>Workload optimisation via better scheduling</i> <sup>149</sup>	Azure AI dynamically reallocates computing loads between servers and clusters to balance performance and consumption (avg. raised from 50-60% to 80-90%)	<ul style="list-style-type: none"> <li>reduced consumption by avoiding server overuse</li> <li>reallocated 800 MW</li> </ul>
<b>Amazon</b> <i>Racks and workload optimisation</i> <sup>150</sup>	use of machine learning models to analyse workload profiles, increase balance and overall computing density, reduction of stranded power zones	<ul style="list-style-type: none"> <li>higher computing density and reduced energy waste</li> <li><i>no figures communicated</i></li> </ul>
<b>IBM → Watson</b> <i>Predictive maintenance in own data centres</i> <sup>151</sup>	real-time data analysis to anticipate critical component failures of aging equipment, which are losing efficiency, e.g., fans, UPS, etc.	<ul style="list-style-type: none"> <li>improved availability and reduced consumption peaks due to malfunctions</li> <li><i>no figures communicated</i></li> </ul>
<b>Alibaba Cloud</b> <i>Intelligent power usage by management</i> <sup>152</sup>	prediction of future energy needs, with adjustments based on the type of tasks to be performed, allow to smoothen consumption peaks which are costly and inefficient	<ul style="list-style-type: none"> <li>better energy use and reduced PUE, with real-time improvement of cooling</li> <li><i>no figures communicated</i></li> </ul>
<b>Meta / facebook</b> <i>Integration with renewable energy sources</i> <sup>153</sup>	plan non-critical workloads according to availability of solar/wind, to maximise the use of renewable energy due to its variable availability	<ul style="list-style-type: none"> <li>improved self-consumption rate for renewable energy</li> <li><i>no figures communicated</i>, but mentioned as marginal contribution</li> </ul>
<b>Schneider Electric EcoStruxure</b> <i>Simulation and optimise design</i> <sup>154</sup>	AI-assisted simulation to predict heat flows and optimise equipment layout at the physical design phase, e.g. rack layout, air flows; multi-parameters real-time cooling regulation	<ul style="list-style-type: none"> <li>efficiency gains at <b>design phase</b></li> <li>reduction in poorly managed hot and cold spots</li> <li>cooling costs -10% to -20%</li> </ul>
<b>OVH on OVHcloud</b> <i>AI for infrastructure and R&amp;D</i> <sup>155</sup>	use of machine learning for maintenance, workload filling prediction, and management of temperature variations	<ul style="list-style-type: none"> <li>anticipate server unavailability</li> <li>improve thermal stability</li> </ul>

<sup>148</sup> [DeepMind AI Reduces Google Data Centre Cooling Bill by 40%](#), DeepMind blog post, July 2016.

<sup>149</sup> [Sustainable by design: Innovating for energy efficiency in AI](#), Microsoft blog post, 12 September 2024

<sup>150</sup> [What is AIOps?](#) and [AWS Sustainable Infrastructure](#), Amazon Web Services (AWS), 2024.

<sup>151</sup> [IBM Services Teams with CBRE to Deliver 'Smart Maintenance' Services to Datacenter Clients](#), HPC wire news, 2020.

<sup>152</sup> [Intelligent Power Management System: Structure, Specifications, and Common Industry Applications](#), Alibaba website.

<sup>153</sup> [META sustainability](#), Meta

<sup>154</sup> [AI – the power behind sustainable future](#), Schneider Electric, April 2025.

<sup>155</sup> [OVH Strengthens Position as Major Player in Artificial Intelligence](#), OVH press release, 2 June 2019.

The following section provides insights from the statements made by hyperscalers around the applicability of AI-based projects to improve energy efficiency in data centres, based on a limited sample size of research, but showing consistent outcomes:

- in most cases, the reported improvements are related to aspects where **innovation or efficiency introduced by AI remains marginal or incremental**, especially compared to more widespread and conventional techniques and methodologies which have already demonstrated a high degree of effectiveness, e.g. improvements along the energy consumption chain to achieve **excellent PUE scores**, and mainly focusing on reducing the PUE denominator (total energy consumption of data centre facility);
- many of the statements referring to environmental-friendly AI usage focus on improving the energy consumption of the **infrastructure designed to run AI solutions**;
- the initiatives that provide figures mostly refer to improving **cooling and chilling**;<sup>156</sup>
- **workload management** is referred with a wider range of benefits, including improved service availability (anticipating failures), spreading or concentrating workloads (opposed strategies), and extending equipment lifetime (until failure rate thresholds are anticipated);
- frequently, it is difficult to separate **what is actually achieved thanks to AI-based tools** as compared to traditional techniques. The figures provided by hyperscalers are not independently verified, and AI-related initiatives are often named among several other unrelated initiatives, making it difficult to isolate energy efficiency improvements from sustainability objectives (such cases are marked as *'no figures communicated'* in Table 18 on the previous page);
- among self-reported figures, **Google** has provided most detailed information and documented initiatives for more than 10 years, e.g., **DeepMind initiative** was trained on data from 120+ parameters, reducing cooling energy requirement by 40%, and improving PUE by 15%;
- currently, the most innovative and practical use of AI is related to real-time data analysis based on a large number of parameters, particularly in a context characterised by uncertainty and poor predictability. In such circumstances, **machine learning models** can significantly outperform traditional methods because they are capable of analysing large volumes of reliable historical data (via unsupervised training), while also incorporating knowledge of corrective measures taken to improve energy efficiency (via supervised/reinforcement training).

Although the use of AI-based tools to improve energy performance in data centres is certainly a promising area of research that is already applied in practical use cases with encouraging results, further evidence is still needed to clearly demonstrate where AI or machine learning solutions have significantly improved actual data centre sustainability beyond the results achieved through well-established and tested traditional methods.

#### FURTHER READING

- **International Energy Agency (IEA):** [World Energy Outlook Special Report – Energy and AI, 2025](#)
- **IBM:** [The power of AI & Automation: Proactive IT, 2023](#)
- **Nvidia:** [AI Factories Are Redefining Data Centres, 2025](#)

<sup>156</sup> In data centre context, **cooling** refers to heat reduction by using **air cooling, liquid cooling or free cooling**, whereas **chilling** refers to a specific type of cooling where temperature is reduced to a range above freezing, typically below 8°C.

# *GENERAL CONSIDERATIONS TO IMPROVE DATA CENTRE ENERGY EFFICIENCY*



# 5. GENERAL CONSIDERATIONS TO IMPROVE DATA CENTRE ENERGY PERFORMANCE

Modern data centres are defined by a **holistic approach** to the management of **energy efficiency**, and **environmental impacts**. At the same time, it is important to put these aspects into a larger context and **consider the lifecycle** of data centre elements or components, such as building design and construction or the lifecycle of IT equipment from manufacturing to recycling or reuse. Although technologies are essential, sustainability must become an **integral part and core value**, informing organisational strategy and every decision from design to daily operation, supported by ambitious action plans and auditable targets.

This chapter presents **insights and recommendations** from research and best practices of data centre operators, ranging from infrastructure optimisation and integration of renewable energy sources to considerations related to managing own data centre facility versus using cloud technologies.

## 5.1. OPTIMISING DATA CENTRE OPERATIONS

- 5.1.1. IT solutions to measure, control and improve energy performance
- 5.1.2. Workload optimisation via IT infrastructure
- 5.1.3. Managing excess heat
- 5.1.4. Maximising free cooling

## 5.2. ADDING RENEWABLE ENERGY TO THE POWER SUPPLY MIX

- 5.2.1. External sourcing
- 5.2.2. On-site power generation

## 5.3. MANAGING OWN FACILITY VERSUS USING SERVICE PROVIDERS

## 5.1. OPTIMISING DATA CENTRE OPERATIONS

The approaches and best practices listed in this chapter are meant to provide a concise overview of the wide range of options for improving the energy efficiency of data centres covered in this report. Those who want to take a more comprehensive approach should consult the ISO/IEC standard series 22237 on data centres facilities and infrastructures.

### ***ISO/IEC standard series 22237 on data centres facilities and infrastructures***<sup>157</sup>

Developed by ISO, this international standard series provides a comprehensive framework covering the **entire lifecycle** of data centre infrastructure **from design and construction to operation** and performance assessment, focusing on improving aspects related to availability, resilience and energy efficiency. Perhaps most importantly, this series **complements the ISO 30134 series on data centre KPIs** that were covered in the first chapter of this report.

The constituent parts of this series **define requirements and best practices** for the main technical components of a data centre, from building design and construction to **electrical power supply** and distribution systems. Furthermore, the standards also specify requirements for **environmental control systems** (e.g., cooling and airflow management), telecommunications cabling infrastructure, and physical security systems (i.e., protection against unauthorized access, fire, and environmental hazards). Finally, the standard also provides guidance on operational and management processes to ensure reliability, risk management, and efficient operation.

Smarter design and operational practices are key to optimising data centre energy efficiency and overall sustainability. The following actions address cooling optimisation, workload management and infrastructure design to optimise energy use and reduce environmental impact.

- application of **ecodesign principles in facility layout and construction**, leveraging local, low-carbon materials and modular infrastructures to reduce environmental footprint;<sup>158</sup>
- **continuous improvement supported by KPIs** and driven by routine internal/external audits;
- adoption of advanced technologies such as **high-voltage direct current (HVDC) architectures** to minimise energy conversion losses;
- implementation of **smart cooling systems**, e.g., liquid cooling and optimised airflow design;<sup>159</sup>
- **on-site low-carbon power generation** solutions, e.g., hydrogen-powered solid oxide **fuel cells**;
- preference for **renewable energy sources** and redundancy in supply contracts to enhance both sustainability and energy security;
- focus on waste reduction and recycling, including server and component **end-of-life strategies**;
- enabling **deep sleep modes** for UPS inverters;
- monitoring **hotspots**;
- set **temperature and humidity targets** to maintain server warranties, but select servers with wider operating envelopes for environmental conditions, e.g., ASHRAE standards.<sup>160</sup>

For more practical applications, please refer to section 3.2.3. on page 52 of this report for an overview of EU-funded projects dealing with energy-efficient architecture and operations.

<sup>157</sup> [ISO/IEC 22237-1:2021](#) on data centre facilities and infrastructures.

<sup>158</sup> For more information, please refer to dedicated [BodenTypenDC](#) project website.

<sup>159</sup> For more information, please refer to dedicated [HeatWise](#) project website.

<sup>160</sup> **ASHRAE**: American Society of Heating, Refrigerating and Air Conditioning Engineers: [Data Center Resource Page](#).

### 5.1.1. IT solutions to measure, control and improve energy performance

- strategic **alignment between operational IT and facilities management teams** to coordinate energy efficiency monitoring and continuous optimisation;
- integration of **building management systems** for real-time tracking and optimisation of facility energy performance;
- deployment of advanced **monitoring platforms** capturing detailed information on power usage, together with environmental and other relevant operational metrics;
- using **KPIs** for actionable **benchmarking and reporting**, e.g., PUE REF, ERF, WUE;
- use of **real-time data analytics**, and automated **energy management systems** for simulations and dynamic optimisation of workload and cooling;
- adoption of automation and **AI solutions for predictive or adaptive workload management**, cooling, and resource allocation;
- integration of **resource effectiveness scoring tools** to quantify and visualise improvement opportunities, e.g., *data centre resource effectiveness (DCRE)*, a holistic metric which takes into account the complex interrelationship of resources consumed by data centres and measures effectiveness by incorporating multiple factors, such as energy efficiency, water usage, water stress and climate zones.<sup>161</sup>

### 5.1.2. Workload optimisation via IT infrastructure

- **ecodesign principles** and **sustainable procurement guidelines** to ensure long-term reduction of the environmental footprint;<sup>162</sup>
- consideration of **hardware scalability, modularity, and virtualisation**, allowing applications to match resource consumption to real demand;
- prioritisation of lightweight, **resource-optimised software** to minimise unnecessary hardware cycling and energy use;
- consolidation of **workloads** to reduce idle hardware and increase utilisation rates, supported by containerisation or serverless architectures.

### 5.1.3. Managing excess heat

Capturing and reusing the heat produced by data centre IT infrastructure contributes to broader decarbonisation efforts beyond the data centre facility, e.g. in urban heating networks.

- implementation of **waste heat recovery** systems, capturing and redirecting excess thermal energy to local district heating networks;
- use of external **CO<sub>2</sub> heat pumps** to integrate data centre heat into district heating systems;
- development of custom **immersion cooling systems**, using phase change materials (PCMs) for high-grade excess heat delivery.

For more practical applications, please refer to section 3.2.2. on page 52 of this report for an overview of EU-funded projects dealing with waste heat valorisation.

<sup>161</sup> [WP#93 Data Center Resource Effectiveness \(DCRE\) v1 Metric](#), The Green Grid's DCRE Standing Work Group, 2025.

<sup>162</sup> [Handbook of Sustainable Design of Digital Services](#), created by Institutes for Sustainable IT, 2021.

#### 5.1.4. Maximising free cooling

Free cooling offers the benefit of a dramatic reduction in total facility energy use, delivering operational cost savings. However, it requires robust air filtration systems to counteract issues from outside air intake. Free cooling initiatives include:

- continuous **temperature and humidity monitoring** to balance free cooling with IT equipment reliability;
- utilisation of natural air and/or **evaporative cooling**, eliminating the need for refrigerants and significantly reducing energy consumption;
- considering local climate conditions in **site selection** to increase '*free cooling*' opportunities;
- innovative architectural **design** for data centre facility, e.g., EU-funded project **BodenTypeDC** utilised free cooling techniques to achieve sub-1.1 levels of PUE;<sup>163</sup>
- indirect free cooling – through a **heat exchanger** – when the outside air may be polluted by dust, particles, or exhaust gases;
- adoption of **hybrid cooling models** combining free cooling with liquid immersion techniques in periods of unfavourable ambient conditions;
- simulate **airflows and cooling** using computational fluid dynamics (CFD) and perform physical measurements to calibrate models;
- implement **containment** within hot or cold corridors;
- regularly verify that **air distribution** is efficient;
- ensure that **heat exchangers** are properly maintained and cleaned, to prevent condenser or evaporator from fouling due to dust.

For more practical applications, please refer to section 3.2.3. Energy-efficient architecture and operations on page 52 of this report for an overview of related EU-funded projects.

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<sup>163</sup> For more information, please refer to dedicated [BodenTypenDC](#) project website.

## 5.2. ADDING RENEWABLE ENERGY TO THE POWER SUPPLY MIX

There are different types of approaches for adding electricity from renewable sources to **diversify power supply** for data centre's electricity consumption: external and on-site solutions.

### 5.2.1. External sourcing

To achieve a more environmentally sustainable mix of electricity supply, **electricity purchasing strategies** can prioritise renewable energy that will reduce carbon footprint, while also ensuring cost predictability and supply resilience. This can be done through the following options:

- **power purchase agreements (PPA)**: long-term contractual arrangements for purchasing electricity from a dedicated renewable energy plant to cover a specified share of the data centre's energy needs. PPAs ensure synchronicity between generated and consumed renewable energy and are well suited for the predictable energy use profiles of data centres;
- **energy attribute certificates**: guarantees of origin (GoO) or renewable energy certificates (REC) represent the environmental attributes of electricity purchased on the open market.

### 5.2.2. On-site power generation

Alternatively, a data centre can **generate its own electricity** through on-site installations, such as solar panels, wind turbines, etc. This requires a dedicated installation and **synchronisation** of power production and consumption to enable switching to generator in case of disruptions.

Although more independent, this approach introduces challenges related to **intermittency** and may require responsive management of IT operations to ensure flexible reallocation of workload or expensive **storage solutions** for energy balancing, see section 4.1 on page 56 for an overview of emerging technologies, e.g., hydrogen storage and fuel cells.

### **Self-consumption v. self-production capacity of on-site power installations**

The on-site power installation can be evaluated from two perspectives:

<b>A. self-consumption capacity</b>	<p><b>On-site consumed production</b>: share of renewable electricity produced on site and consumed by the site itself during a specified period. If there is no storage capacity, the rest of the production must be injected into an external electrical network.</p> <p><b>Total production</b> is the quantity of electricity produced by the on-site renewable energy power plant, during the same period.</p>
<p>A <b>100% self-consumption rate</b> is achieved if the site is able to absorb the entirety of the produced renewable electricity. A rate below 100% means that a part of the produced electricity must be sold (or given) to an energy operator.</p>	
<b>B. self-production capacity</b>	<p>The ratio reflects the level of <b>autonomy of a site</b> to satisfy its needs with its own renewable energy production.</p> <p><b>Total consumption</b> is the total electricity consumed by the data centre, during the same period.</p>
<p>In the case of data centres, a 100% self-production rate is <b>not possible</b>, as it would require a mix of different renewable sources and large storage capacities.</p>	

## 5.3. MANAGING OWN FACILITY VERSUS USING SERVICE PROVIDERS

The following section provides a SWOT analysis comparing the strategic and operational implications of owning and managing a dedicated data centre facility versus using colocation or co-hosting service providers. Table 19 below offers a comparison of three options:

- on-premises data centre,
- co-location,
- public cloud platform.

**Table 19. SWOT analysis: data centre ownership versus hosted infrastructure services<sup>164</sup>**

<b>STRENGTHS<sup>165</sup></b>		
on-premises data centre	co-location data centre	public cloud platform (hyperscalers)
<p><b>Full control and customisation:</b> Complete control over facilities, infrastructure, and operations allows for tailored energy efficiency solutions. Can design and implement specific cooling systems (e.g., free cooling, liquid cooling), power management strategies, and renewable energy integrations to meet unique organisational goals and compliance requirements. <a href="#">[ResearchHQ / Odata]</a></p>	<p><b>Shared infrastructure and economies of scale:</b> Co-location providers operate large, modern, and purpose-built facilities, benefiting from economies of scale. This often results in a lower PUE and more efficient cooling and power distribution systems than a typical on-premises facility. <a href="#">[EziBlank / Open Compute Project]</a></p>	<p><b>Potentially highest energy efficiency and PUE:</b> Hyperscale cloud providers like Google and Microsoft announce some of the most energy-efficient data centres in the world (on some of their data centres), with PUEs significantly lower than industry averages. <a href="#">[Open Compute Project]</a></p> <p>They invest heavily in R&amp;D for innovative cooling, power, and server technologies. <a href="#">[IEA 4E]</a></p>
<p><b>Direct sustainability initiatives:</b> Ability to directly invest in and showcase sustainability efforts, e.g., installing on-site renewable energy sources (solar, wind) or implementing waste heat recovery for local buildings. This provides a strong brand narrative and can support local community relations.</p>	<p><b>Access to expert management and technology:</b> Tenants gain access to the colocation provider's specialized expertise and advanced energy-efficient technologies, such as hot/cold aisle containment, advanced airflow management, and efficient UPS systems, without the capital expenditure and operational burden of managing them. <a href="#">[DataBank]</a></p>	<p><b>High server utilisation and resource sharing:</b> The multi-tenant nature of the public cloud allows for high server utilisation rates, a key factor in reducing energy consumption per workload. Resources are dynamically allocated, eliminating the inefficiency of idle or underutilized servers found in many private data centres. <a href="#">[IBM / Jones Day]</a></p>
<p><b>Data sovereignty and compliance:</b> For industries with strict data residency and security requirements, an on-premises model ensures complete control over data location, which is a key aspect of meeting certain sustainability and regulatory mandates. <a href="#">[Oracle]</a></p>	<p><b>Scalability and flexibility:</b> Colocation offers the ability to scale up or down space, power, and cooling as needed, which helps optimize resource utilisation and prevent the energy waste associated with underutilized on-premises facilities. <a href="#">[ServerLIFT]</a></p>	<p><b>Extensive renewable energy and carbon offsetting:</b> Public cloud providers are leading the market in corporate PPAs and have ambitious goals for running on 100% renewable energy. They provide customers with own tools and reports to track and report their carbon footprint, allowing them to leverage the provider's green credentials. <a href="#">[Credence Research / Jones Day]</a></p>

<sup>164</sup> The full references to sources for the SWOT analysis are provided in Table 20 on page 85.

<sup>165</sup> Sources: [Credence Research](#), [DataBank](#), [EziBlank](#), [IEA 4E](#), [IBM](#), [Jones Day](#), [ResearchHQ](#), [Odata](#), [Open Compute Project](#), [Oracle](#), [ServerLIFT](#).

WEAKNESSES <sup>166</sup>		
on-premises data centre	colocation data centre	public cloud platform (hyperscalers)
<p><b>High capital and operating costs:</b> Building and maintaining a modern, energy-efficient data centre is a massive capital expenditure (CapEx). Ongoing operational costs for power and cooling are high, and the facility may become outdated and inefficient over time. <a href="#">[ResearchHQ]</a> / <a href="#">EziBlank</a></p>	<p><b>Limited control over facilities and strategy:</b> tenant has no control over core facility infrastructure (power grid, cooling systems, building design); while they benefit from provider's efficiency, they cannot make their own changes to underlying infrastructure or directly influence the provider's sustainability strategy beyond what is offered. <a href="#">[EziBlank]</a></p>	<p><b>Lack of direct control:</b> Customers have no direct control over the physical infrastructure or how it is managed. They cannot implement their own efficiency measures on the hardware level and are entirely reliant on the provider's strategy and technological stack. <a href="#">[IBM]</a></p>
<p><b>Inefficiency and underutilisation:</b> Many on-premises data centres are inefficient due to legacy equipment, poor cooling layouts, and low server utilisation rates (often &lt;30%), leading to significant energy waste and high PUE. <a href="#">[Ofcom]</a></p>	<p><b>Lack of transparency:</b> While colocation providers often publish PUE, the tenant may have less granular insight into the energy consumption of their specific equipment or the facility's overall sustainability metrics compared to managing it themselves. Power bills can also be a source of a lack of transparency. <a href="#">[ResearchHQ]</a></p>	<p><b>Indirect and opaque sustainability:</b> While cloud providers announce to have strong sustainability programs, the customer's contribution is indirect. They are consuming a service, not directly controlling the energy usage. The carbon footprint data provided by cloud providers, while helpful, is a "black box" and does not provide the required level of comprehensiveness of impact. <a href="#">[Credence Research]</a></p>
<p><b>Limited access to expertise:</b> small to medium-sized organisations may lack the specialized staff and resources required to implement and manage advanced energy-saving technologies like liquid cooling or AI-driven power management systems.</p>	<p><b>Potential for 'hidden' costs:</b> While operating costs are generally lower than on-premises, tenants pay for a share of the facility's power and cooling costs, which can fluctuate. Inefficient airflow or poorly managed tenant equipment can indirectly increase the tenant's bill. <a href="#">[EziBlank]</a></p>	<p><b>Vendor lock-in and cost volatility:</b> although pay-as-you-go model is flexible, long-term costs can become prohibitive for stable workloads. Migrating large datasets/applications between cloud providers is complex and costly, creating a risk of vendor lock-in. <a href="#">[Ofcom]</a> / <a href="#">EziBlank</a></p>

OPPORTUNITIES <sup>167</sup>		
on-premises data centre	colocation data centre	public cloud platform (hyperscalers)
<p><b>Modernisation and retrofitting:</b> Significant opportunities exist to improve efficiency by modernising legacy facilities with modern technologies like free cooling, improved containment, and intelligent power management systems. <a href="#">[Odata]</a> / <a href="#">DataBank</a></p>	<p><b>Leveraging provider's innovations:</b> Tenants benefit from ongoing innovations and investments in energy-efficient technologies by service providers, e.g., new cooling systems, AI for energy management, better power distribution. <a href="#">[174 Power Global]</a> / <a href="#">DataBank</a></p>	<p><b>AI and machine learning optimisation:</b> Cloud providers are at the forefront of using AI and ML to dynamically manage and optimize energy use, cooling, and workload distribution, which continuously improves efficiency for all customers. <a href="#">[DataBank]</a></p>
<p><b>Integration with corporate goals:</b> Can directly align data centre strategy with broader corporate sustainability goals, showcasing tangible progress on sustainability metrics. <a href="#">[Odata]</a></p>	<p><b>Hybrid cloud and IT strategy:</b> Colocation can serve as a key component of a hybrid IT strategy, allowing organisations to retain legacy, specialized, or sensitive workloads on-site while moving less critical or variable workloads to the public cloud for efficiency. <a href="#">[Digital Realty]</a></p>	<p><b>Choose footprint and green regions:</b> customers can deploy workloads in regions with cleaner energy grids, such as those with high renewable or nuclear power generation, and move workloads to follow daylight for solar power, a so-called 'cloud smart' strategy. <a href="#">[174 Power Global]</a></p>
<p><b>Waste heat recovery:</b> if a significant need to heat is present in the vicinity, the on-premises model presents a direct opportunity to implement waste heat recovery systems for heating office buildings or other on-site facilities, creating a circular energy economy. <a href="#">[Odata]</a></p>	<p><b>Access to renewable energy PPAs:</b> Many colocation providers are now offering or building facilities with access to large-scale renewable energy PPAs, allowing tenants to benefit from clean energy without direct investment. <a href="#">[174 Power Global]</a></p>	<p><b>Simplified sustainability reporting:</b> Public cloud platforms provide integrated tools that allow customers to easily track and report on their carbon footprint and sustainability metrics, a major advantage for companies needing to meet sustainability reporting requirements. <a href="#">[Credence Research]</a></p>

<sup>166</sup> Sources: [Credence Research](#), [EziBlank](#), [IBM](#), [ResearchHQ](#), [Ofcom](#).

<sup>167</sup> Sources: [174 Power Global](#), [Credence Research](#), [DataBank](#), [Digital Realty](#), [Odata](#).

THREATS <sup>168</sup>		
on-premises data centre	colocation data centre	public cloud platform (hyperscalers)
<p><b>Regulatory and compliance pressures:</b> new regulations in U.S. and Europe (Energy Efficiency Directive, Taxonomy Regulation), are imposing stricter requirements and reporting mandates on data centres; on-premises operators face the burden of ensuring that their facilities meet these standards. <a href="#">[Jones Day / Open Compute Project]</a></p>	<p><b>Power and cost volatility:</b> generally more efficient, colocation facilities are not immune to rising energy costs, which are often passed directly to the tenant. The increasing power demands of AI and other high-density workloads can strain infrastructure and lead to higher costs. <a href="#">[174 Power Global]</a></p>	<p><b>'Cloud green washing' and misleading metrics:</b> there is a risk of "cloud washing," where providers overstate their sustainability claims, making it difficult for customers to verify the actual environmental impact of their workloads. <a href="#">[Ofcom]</a></p>
<p><b>Energy cost volatility:</b> high energy prices and grid constraints in many regions pose a significant threat to the operational costs and financial viability of on-premises data centres. <a href="#">[Savills / 174 Power Global]</a></p>	<p><b>Lack of standardisation:</b> wide variation in energy efficiency and sustainability commitment of different providers; lack of standardised metrics or reporting can make it difficult for tenants to compare options effectively. <a href="#">[Open Compute Project]</a></p>	<p><b>Indirect costs of power:</b> while customers don't directly pay for power, it's baked into service costs. This can make it difficult to fully grasp the energy consumption of a workload and identify opportunities for optimisation. <a href="#">[EziBlank]</a></p>
<p><b>Talent shortage:</b> shortage of skilled data centre technicians and engineers makes it difficult to effectively manage and optimize the facility for maximum energy efficiency, leading to potential operational and sustainability risks. <a href="#">[Oracle]</a></p>	<p><b>Vendor dependency:</b> companies become dependent on their colocation provider for critical infrastructure. If the provider fails to maintain or upgrade their facility to meet new efficiency standards, the tenant's sustainability goals could be jeopardized. <a href="#">[ServerLIFT]</a></p>	<p><b>Geopolitical and data security concerns:</b> concerns about data sovereignty, especially in Europe, may push some companies towards more local or private solutions, even if they are less efficient. Regulations like GDPR can make reliance on a US-based cloud provider's global infrastructure a threat. <a href="#">[Jones Day / Oracle]</a></p>

When it comes to hyperscalers, energy efficiency must be analysed in conjunction with **scale of use**, because if a large data centre has a very high use rate, its **overall environmental footprint** will have a much more detrimental impact compared to the benefit derived from improvements in energy efficiency. Take the example of **Ireland**, where five major global tech companies: Google, Amazon, Facebook, Apple, and Microsoft (GAFAM) have installed large-scale data centres due to a favourable business environment. As a consequence of their operations, Dublin region grid reached its capacity, prompting the regulator to impose a moratorium in 2021 that halted new grid connections amid a sharp surge in electricity consumption from the sector.<sup>169</sup> According to a recent report, data centres accounted for **21.2% of all electricity demand** in 2024. Comparing the change in annual electricity demand from 2015 to 2024, data centres are responsible for 88.2% of the increase in Ireland's electricity demand during that period.<sup>170</sup> However, this impact is not captured in the sustainability reports of hyperscalers, as much of it occurs beyond their data centre boundaries.<sup>171</sup>

## FURTHER READING

- Boavizta (2024) [Assessment of the environmental footprint of the Public Cloud](#)
- Climatiq (2025) [Clouding the issue: Are Amazon, Google, and Microsoft really helping companies go green?](#)

<sup>168</sup> Sources: [174 Power Global](#), [EziBlank](#), [Jones Day](#), [Ofcom](#), [Open Compute Project](#), [Oracle](#), [Savills](#), [ServerLIFT](#).

<sup>169</sup> [Ireland unveils strict new rules for data centre power use](#), DataCentreNews UK, 30 January 2026.

<sup>170</sup> [Energy in Ireland 2024](#), Sustainable Energy Authority of Ireland ([SEAI](#)), December 2025.

<sup>171</sup> [Data center emissions probably 662% higher than big tech claims](#), The Guardian, 15 September 2024.

Table 20. Sources for SWOT analysis presented in Table 19 on page 72

### FURTHER READING

- **174 Power Global:** [\*Why Colocation Data Centres Need Smarter Energy Solutions\*](#)
- **Accenture:** [\*Internet of Clouds\*](#) (2023) and [\*Sovereign Cloud Comes of Age in Europe\*](#) (2023)
- **Capgemini:** [\*World Cloud Report 2023\*](#) (2023) and [\*Journey to Cloud Sovereignty\*](#) (2022)
- **Contemsa:** [\*The Big BIG Cloud Report\*](#) (2018)
- **Credence Research:** [\*U.S. Data Centre Power Management Market, 2024–2032\*](#)
- **DataBank:** [\*Optimizing Data Centres for Energy Efficiency\*](#) (2024)
- **Digital Realty:** [\*A Guide to Data Centre Terms\*](#) (2023)
- **EziBlank:** [\*Colocation vs. Cloud Data Centres: Which One Is Right for Your Infrastructure?\*](#)
- **IBM:** [\*What Is a Data Centre?\*](#)
- **IEA 4E EDNA:** [\*Data Centre Energy Use: Critical Review of Models and Results\*](#) (2025)
- **Jones Day:** [\*Green Data Centres: Pioneering Energy Efficiency and Sustainability in the EU\*](#) (2025)
- **Odata:** [\*Data Centre energy efficiency: 5 steps to maximize sustainability and reduce costs\*](#)
- **Ofcom:** [\*SDIA: Building a Sustainable, Federated European Cloud: A Vision for Europe\*](#) (2022)
- **Open Compute Project:** [\*The Current State of Data Centre Energy Efficiency in Europe\*](#) (2024)
- **Oracle:** [\*10 Steps to an Effective Data Centre Strategy\*](#) (2025)
- **ResearchHQ:** [\*The Pros and Cons of On-Prem vs. Colocation vs. Cloud vs. Edge\*](#)
- **Savills:** [\*European Data Centres: Navigating the new data-centric frontiers\*](#) (2024)
- **ServerLIFT:** [\*Colocation or No? A SWOT Analysis for Utilizing Colocation Facilities\*](#) (2022)

# CONCLUSION



## CONCLUSION

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Improving data centre sustainability requires a holistic, data-driven, and organisation-wide approach. The most effective organisations combine technical optimisation and robust monitoring based on solid and transparent metrics to support continuous improvement, rather than relying on isolated or short-term measures. In practice, success in improving energy efficiency depends on treating it not as a technical constraint, but as a **core operational and strategic priority** across the entire lifecycle of a data centre. Here are some of the most important measures that data centre operators can implement in order to improve energy performance and overall sustainability:

- **Adopt a system-wide, integrated optimisation approach.** Significant energy efficiency improvements cannot be achieved through isolated actions. Organisations should avoid siloed optimisation approaches, and instead consider the entire data centre facility, from power distribution and IT equipment to backup systems and cooling, supported by coordinated operational management.
- **Establish continuous monitoring and KPI-driven management.** Effective improvement depends on systematic measurement and control. High-performing organisations rely on real-time monitoring, standardised KPIs (e.g., PUE, WUE, REF, ERF), and regular audits to guide decisions and track progress.
- **Integrate sustainability into organisational strategy and governance.** Sustainability must move beyond technical improvements and become a core organisational objective, embedded in strategy, planning, and decision-making processes based on clear, transparent and well-established metrics that can support data-driven progress.
- **Optimise cooling and infrastructure design.** Cooling remains a major contributor to energy consumption in data centres. Significant gains can be achieved through efficient thermal management (e.g., free cooling) and infrastructure design (e.g., airflow optimisation).
- **Increase the share of renewable energy and optimise energy sourcing.** Energy sourcing is a critical sustainability component as measured by REF. Organisations should actively transition to renewable energy and adjust sourcing strategies to prioritise renewable electricity (on-site or off-site), in conjunction with supplier selection based on renewable options.
- **Improve IT efficiency and workload management.** Energy efficiency is not only a facilities issue, as IT operations play a critical role as well. Energy use can be significantly reduced by optimising computational workload distribution and resource utilisation in the data centre, which can be achieved using innovative AI-solutions for real-time monitoring and anomaly detection.
- **Leverage advanced technologies cautiously and effectively.** Technologies such as AI, automation, and advanced analytics can help improve efficiency, but only when properly integrated into operational processes. For instance, AI is currently especially effective for predictive maintenance and dynamic workload optimisation.
- **Reuse energy and minimise resource waste.** Sustainability requires going beyond energy efficiency to include resource optimisation and circular approaches such as implementing waste heat recovery where feasible (as measured by ERF), or minimising water consumption through the constant monitoring of WUE. Recycling and lifecycle management for equipment should also be adopted.

# ANNEXES



## Annex I. SURVEY QUESTIONNAIRE

### A. Operational, planning and strategic topics

#### 1. Practices for measuring, monitoring, controlling and optimising the energy footprint

- What high-level KPIs do you use to accurately measure the data centre's energy footprint?
- How is real-time monitoring of energy consumption organised (monitoring tools, sensors, software)?
- What energy audit procedures (internal or external) have you put in place to assess performance on a regular basis?
- Main conclusions from the last energy audit ?
- What corrective actions or optimisations have you already implemented, and what results have they generated?
- How do you incorporate feedback and historical data to continually improve your energy management practices?

#### 2. Global energy strategy and IT

- Is the data centre's energy policy integrated into the company's overall strategy? If so, how?
- Do you have a specific roadmap with short, medium and long-term carbon footprint reduction targets?
- What specific KPIs do you use to monitor and evaluate the energy performance of your IT infrastructures?
- How does your IT strategy consider the development of green technologies and eco-efficient solutions?
- What internal collaborations or external partnerships have you put in place to encourage a sustainable and innovative approach to energy?

#### 3. Energy supply sources and contracts

- What are the main energy supply sources and what proportion of renewable energy does your energy mix represent?
- Do you have specific contracts or agreements encouraging the purchase of green and sustainable energy?
- How do you assess the environmental impact of different suppliers, and what steps are taken to verify this?
- What pricing or economic incentive mechanisms (subsidies, preferential tariffs) have been negotiated to encourage energy efficiency?
- How does the diversification of energy sources contribute to the resilience and sustainability of your supply?

#### 4. Operational, regulatory and other constraints

- What regulatory constraints (local, national or international) currently impact your energy policy?
- How do you integrate environmental requirements and standards into the day-to-day management of your operations?
- What are the main operational difficulties encountered when implementing energy optimisation measures?
- Are there any technical limitations or infrastructure obstacles to reducing your energy footprint?
- How do you anticipate and prepare for future changes in energy regulations in order to remain compliant?

#### 5. Energy purchasing policy and infrastructure renewal

- To what extent does your energy procurement policy incorporate sustainability and carbon reduction criteria?
- How do decisions to renew or extend infrastructure take energy efficiency into account?
- Do you have indicators to measure the environmental impact of your investments in equipment and infrastructure?
- What innovations or technologies do you plan to adopt to improve energy efficiency when renewing your facilities?
- How do you assess the return on investment (ROI) of projects aimed at reducing energy consumption and optimising the overall footprint?

#### 6. Other related areas

- What cooling and thermal management strategies have you implemented to reduce the energy consumption associated with the air conditioning and cooling system?
- How do the physical architecture and design of the data centre contribute to greater energy efficiency?
- What staff awareness and training initiatives are in place to promote eco-responsible practices?
- How do you integrate emerging technologies (AI, IoT, automation) into energy management and optimisation?
- Have you obtained or are you considering obtaining certifications (e.g. ISO 50001, ISO 14001) that demonstrate your commitment to energy / environment management?

**B. KPIs (implemented or planned)****1. Common environmental footprint KPIs**

- **PUE**: compares the total energy consumed by the data centre to the energy used specifically by the IT equipment
- **CUE**: measures the carbon footprint by relating CO<sub>2</sub> emissions to the energy consumption of IT equipment
- **WUE**: quantity of water consumed in relation to IT energy
- **renewable energy (%)**: proportion of energy from renewable sources in the data centre's overall energy mix
- **IT load ratio per kWh**: quantifies the load or volume of work carried out per unit of energy consumed
- any other KPIs implemented?

**2. Sustainability KPIs**

- **ESG ROI** (sustainability-adjusted ROI): measures ROI by integrating financial savings (reduced energy costs, optimised maintenance) with environmental and social benefits (reduced CO<sub>2</sub> emissions, community impact)
- **Durability Index** (ratio of effective life to planned life): compares the actual life of infrastructure or equipment to their initially planned life
- **Material Recyclability and Circularity Index**: assesses the proportion of equipment and materials that can be recycled or reused at the end of their life
- **Sustainable certification and labelling**: measures the percentage of investments that have obtained recognised certifications, e.g. ISO 50001, LEED, BREEAM
- **Energy Efficiency Reinvestment Rate**: calculates the proportion of savings or profits generated by the investment that is reinvested in projects to improve energy efficiency or modernise infrastructure
- any other KPIs implemented?

**3. KPIs integrating innovation, technology, automation and AI**

- **Energy process automation (%)**: measures the proportion of operations (monitoring, diagnostics, control and predictive maintenance) that are automated using AI solutions or other technologies
- **Energy efficiency improvement through innovation**: compares energy performance indicators (e.g. PUE or kWh consumption per IT load) before and after the implementation of innovative technologies
- **Anomaly response time thanks to AI**: tracks the average time between the detection of an energy anomaly and the implementation of an automated corrective action
- **Emerging technology adoption index**: composite score integrating the number of pilot projects deployed, the rate of operational integration of solutions (AI, IoT, automation) and their measurable impact on key energy KPIs
- **R&D investment in energy innovation**: evaluates the proportion of the budget devoted to the research and development of energy optimisation technologies
- any other KPIs implemented?

## C. Technical and operational characteristics

### 1. Energy security level setup / reliability

- global Tiering level (Tier 1-4)
- on electricity supply
- on cooling facilities
- total emergency supply on generators (yes / no / partial)
- type of generators and maximum power
- quantity of fuel for diesel generators / autonomy (hours)
- maximum external temperature in data centre design
- age of electrical transformers and UPS (years)
- age of chillers (years)
- obsolescence plan / maintenance plan
- thermal camera inspection to identify hot points on servers, bays and aisles, frequency of inspection
- data centre's year of entry into service
- network backbone integration

### 2. Energy monitoring and specific characterisation

<b>PUE</b>	<ul style="list-style-type: none"> <li>▪ average external temperature (or altitude / latitude)</li> <li>▪ what is the datacentre(s) location (country/region/city)</li> <li>▪ what data is available for PUE computation?</li> <li>▪ last PUE calculation date and value</li> <li>▪ can all types of consumption be segregated, e.g. IT (servers / network) from facilities (cold generation chillers, cold distribution, ventilation, transformers, UPS, oil warming for generators, lighting, other)</li> <li>▪ frequency of review: monthly / quarterly / annually</li> <li>▪ is it possible to compare PUE to a reference?</li> <li>▪ (theoretical curve <math>PUE = f(IT \text{ load})</math>? verified curve? yearly rolling value? or monthly comparison with previous years?)</li> </ul>
<b>cooling</b>	<ul style="list-style-type: none"> <li>▪ annual consumption of refrigerant gases and its type</li> <li>▪ confinement of all aisles (yes / no / partial; hot / cold)</li> <li>▪ cold air loop: temperature of blown cold air / temperature of hot intake air</li> <li>▪ free cooling (or free chilling) system (yes/no)</li> <li>▪ heat recovery – type of valorisation for the produced heat and used vector (fluid) / heat usage</li> <li>▪ what is the limiting envelope of warranty from the manufacturer (temperature/humidity)?</li> </ul>
<b>electricity</b>	<ul style="list-style-type: none"> <li>▪ number of infrastructure servers respecting the ASHRAE A4 standard / A3 standard / none</li> <li>▪ type of electrical transformers (<i>A0AK standard?</i>)</li> <li>▪ use of local renewable electricity production</li> <li>▪ total self-consumption</li> </ul>

## Annex II. EU-FUNDED PROJECTS FROM 2015 TO 2027

This section provides overview of EU-funded projects, under the **Horizon Europe** programme, aimed at improving energy efficiency of data centres, in collaboration with municipalities, utilities and research institutes. Together, they reflect the EU's strategic focus on reducing the environmental footprint of digital infrastructure and offer concrete examples of state-of-the-art practices.

EU FUNDING

1. Cooling and thermal optimisation projects <sup>172</sup>			
<b>COMPUSAPIEN</b>	<b>Computing Server Architecture with Joint Power and Cooling Integration at the Nanoscale</b>		
developed a disruptive 3D server architecture integrating power and cooling at the nanoscale to improve energy efficiency in data centres		2017-2022 Horizon 2020	2 million
<b>ReUseHeat</b>	<b>Recovery of Urban Excess Heat</b>		
integrated excess heat from data centres into low-temperature district heating networks via external CO <sub>2</sub> heat pumps		2017-2022 Horizon 2020	4 million
<b>Submer</b>	<b>Highly Efficient, Eco-friendly Immersion Cooling for Data Centres</b>		
developed and validated an environmentally friendly immersion cooling system for data centres to drastically reduce cooling energy consumption and enhance efficiency		2018-2020 Horizon 2020	1.3 million
<b>REWARDHeat</b>	<b>Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks</b>		
integration of low-grade excess heat, incl. from data centres, into 5th-generation district heating networks, promoting renewable heat use, reducing fossil fuel dependency		2019-2024 Horizon 2020	15 million
<b>WeDistrict</b>	<b>Smart and local renewable Energy DISTRICT heating and cooling solutions for sustainable living</b>		
demonstrated fossil-fuel-free district heating and cooling solutions by integrating renewable sources and waste heat from data centres		2019-2024 Horizon 2020	15 million
<b>HeatWise</b>	<b>Holistic Energy management And Thermal Waste Integrated System for Energy optimisation</b>		
integrated thermal and energy optimisation in high-IT-load buildings, incl. development of hybrid cooling systems and digital twins for workload management		2024-2026 Horizon Europe	3 million
<b>THUNDER</b>	<b>Thermochemical storage Utilisation eNabling Data centre seasonal Energy Recovery</b>		
development of seasonal thermal storage based on thermochemical materials coupled with a high-temperature heat pump for accumulation and reuse of excess heat		2024-2027 Horizon Europe	5.6 million
<b>MODERATOR</b>	<b>Immersion cooling &amp; advanced materials for heat recovery from data centres</b>		
development of a novel immersion-cooling system using phase change materials (PCM) to provide excess heat at 50–65°C for reuse		2024-2027 Horizon Europe	4.3 million
2. Architecture and hardware optimisation projects <sup>173</sup>			
<b>EURECA</b>	<b>EU Resource Efficiency Coordination Action</b>		
tool for public sector data centres to identify and implement energy efficiency measures		2015-2018 Horizon 2020	1.5 million
<b>M2DC</b>	<b>Modular Microserver Data Centre</b>		
developed energy-efficient, flexible, and modular micro server platforms for data centres, focusing on low-power and cost-effective solutions		2016-2019 Horizon 2020	8 million
<b>BodenTypeDC</b>	<b>Prototyping the most energy and cost-efficient data centre in the world</b>		
built and validated a prototype data centre in Sweden achieving PUE below 1.02 by using renewable energy and innovative cooling technologies		2017-2020 Horizon 2020	2.6 million

<sup>172</sup> For more information, please refer to dedicated project websites: [COMPUSAPIEN](#), [HeatWise](#), [MODERATOR](#), [ReUseHeat](#), [REWARDHeat](#), [Submer](#), [THUNDER](#), [WeDistrict](#).

<sup>173</sup> For more information, please refer to dedicated project websites: [BodenTypenDC](#), [EURECA](#), [M2DC](#).

<b>3. Interconnects and photonics for energy efficiency projects</b> <sup>174</sup>			
<b>COSMICC</b>	<b><i>CmOs Solutions for Mid-board Integrated transceivers with breakthrough Connectivity at ultra-low Cost</i></b>		
developed co-packaged optical transceivers for cloud management operating systems (CmOS) to reduce energy-per-bit in data centre interconnects, enabling high-density, low-power optical connectivity at lower cost		<b>2015-2019</b> Horizon 2020	3.7 million
<b>L3MATRIX</b>	<b><i>Large Scale Silicon Photonics Matrix for Low-Power and Low-Cost Data Centres</i></b>		
designed 3D silicon photonics matrix architecture for intra-data centre interconnects to lower power consumption, improve signal integrity, cost-effective scalability for hyperscalers		<b>2015-2019</b> Horizon 2020	3 million
<b>ICT-STREAMS</b>	<b><i>Silicon Photonics Transceiver and Routing technologies for High-End Multi-Socket Server Blades with Tb/s Throughput interconnect interfaces</i></b>		
built silicon photonic technologies for Tb/s interconnects in server blades, enhancing throughput and reducing energy demands in high-performance data centre infrastructure		<b>2016-2019</b> Horizon 2020	3 million
<b>QAMeleon</b>	<b><i>Sliceable multi-QAM format SDN-powered transponders and ROADMs Enabling Elastic Optical Networks</i></b>		
developed low-power photonic transceivers and elastic optical networks for intra- and inter-data centre connectivity, improving energy efficiency in large-scale cloud infrastructures for software-defined networking (SDN)		<b>2018-2022</b> Horizon 2020	8 million
<b>MASSTART</b>	<b><i>MASS manufacturing of TrAnsceiveRs for Terabit/s era</i></b>		
focused on mass production of high-speed, energy-efficient photonic transceivers for next generation data centres, optimising integration, packaging and thermal performance		<b>2019-2023</b> Horizon 2020	6 million
<b>4. Efficient power supply and local energy system projects</b> <sup>175</sup>			
<b>CATALYST</b>	<b><i>Converting DCs in Energy Flexibility Ecosystems</i></b>		
data centre participation in smart energy systems by integrating energy flexibility strategies, incl. demand-response and waste heat valorisation, improving environmental sustainability		<b>2017-2020</b> Horizon 2020	2.3 million
<b>E2P2</b>	<b><i>EcoEdge PrimePower</i></b>		
development of on-site power generation solutions for data centres using solid oxide fuel cells (SOFCs) powered by hydrogen or biogas		<b>2021-2026</b> Horizon 2020	2.5 million
<b>Sovereign Edge.Cognit</b>	<b><i>A Cognitive Serverless Framework for the Cloud-Edge Continuum</i></b>		
developed a cognitive, serverless orchestration framework for the cloud-to-edge continuum, enabling energy-aware workload placement and dynamic scaling across distributed data centres; improved energy efficiency, latency, resilience of federated data centre infrastructures		<b>2023-2025</b> Horizon Europe	6 million
<b>CAPE</b>	<b><i>European Open Compute Architecture for Powerful Edge</i></b>		
modular and open compute architecture design for energy-efficient micro data centres ( <i>edge micro data centre</i> , EMDC), enabling scalable edge computing with reduced power consumption and improved integration with renewable energy sources		<b>2024-2027</b> Horizon Europe	6 million
<b>5. Cloud / Edge workload orchestration projects</b> <sup>176</sup>			
<b>NEPHELE</b>	<b><i>eNd to End scalable and dynamically reconfigurable optical archItecture for application-awarE SDN cLoud datacentres</i></b>		
developed an SDN-enabled (software-defined networking) optical cloud data centre architecture with energy-aware VM placement and dynamic reconfiguration to reduce power consumption and improve scalability across distributed infrastructures		<b>2015-2018</b> Horizon 2020	3 million

<sup>174</sup> For more information, please refer to dedicated project websites: [COSMICC](#), [ICT-STREAMS](#), [L3MATRIX](#), [MASSTART](#), [QAMeleon](#).

<sup>175</sup> For more information, please refer to dedicated project websites: [CAPE](#), [CATALYST](#), [E2P2](#), [SovereignEdge.Cognit](#).

<sup>176</sup> For more information, please refer to project website: [NEPHELE](#).

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