European Commission

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

Second technical report

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1. Introduction

a. Purpose

This document represents the deliverable 'Second Technical Report' for the project Study on Technical Assistance in support of implementing Article 12(5) of Directive 2023/1791 on the energy performance and sustainability of data centres, and has been produced by EY, AIT and Borderstep for the European Commission.

The technical report assesses data centre energy efficiency and sustainability, and the reporting scheme of the Delegated Regulation 2024/1364. It uses reported data, supplemented where necessary, and evaluates energy performance via sustainability and key performance indicators. The report also addresses data quality/completeness and proposes reporting scheme improvements, including information/indicators and user experience.

b. Structure of this report

This document is structured as follows:

- Chapter 1 presents to report introduction.
- Chapter 2 revisits the project methodology of Task 2.
- Chapter 3 reports on the preliminary results.
- Chapter 4 concludes the report.

c. Version control

Version	Date	Description
1.0	June 27, 2025	Preliminary version of the Second Technical Report
2.0	August 29, 2025	Second version of the First Technical Report

d. List of acronyms

Table 1 - List of acronyms

Acronym	
AI	Artificial Intelligence
AIT	Austrian Institute of Technology
BAT	Best Available Technologies
CDD	Cooling Degree Days
CDR	Carbon Dioxide Removal
CEER	Council of European Energy Regulators
CO_2	Carbon dioxide
CoC	Code of Conduct
COP	Coefficient of Performance
CPU	Central Processing Unit
CRAC	Computer Room Air Conditioner
CRAH	Computer Room Air Handler

DG ENER	Directorate-General for Energy
DCESS	Synergies between Data Centres and Energy Systems
ECRB	Energy Community Regulatory Board
EED	Energy Efficiency Directive
EPBD	Energy Performance of Buildings Directive
ERF	Energy Reuse Factor
EY	Ernst & Young
FLOPS	Floating Point Operations per Second
GHG	Greenhouse gas
GoO	Guarantees of Origin
GW	Gigawatt
HVO	Hydrotreated Vegetable Oil
I/O	Input / Output
ICT	Information and Communication Technology
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
KPI	Key Performance Indicator
LAU	Local Administrative Unit
MS	Member State
MPS	Minimum Performance Standards
MW	Megawatt
PUE	Power Usage Effectiveness
PPA	Power Purchase Agreements
PV	Photovoltaic
RED III	Renewable Energy Directive III
REF	Renewable Energy Factor
SKU	Stock Keeping Unit; precise identifier for CPU chips
SERT	Server Efficiency Rating Tool
SPEC	Standard Performance Evaluation Corporation
ToR	Terms of Reference
TPP	Total Processing Performance
TRL	Technology Readiness Level
UPS	Uninterruptable Power Supply
WUE	Water Usage Effectiveness
AI	Artificial Intelligence
AIT	Austrian Institute of Technology

e. List of reference documents

Table 2 - List of reference documents

Source	Type	Name	Link	Summary
German Federal Government	Regulation	Draft Law on Increasing Energy Efficiency and Amending the Energy Services Act	Link	This draft law by the German Federal Government aims to enhance energy efficiency and amend the Energy Services Act. It sets ambitious energy efficiency targets for both primary and final energy consumption in Germany, aligning with the EU's climate goals for 2030. The law includes mandatory energy or environmental management systems for companies with high energy consumption and outlines specific energy-saving measures for public institutions.
European Commission	Technical report	Energy Consumption in Data Centres and Broadband Communication Networks in the EU	Link	It reviews and uses existing literature and public data sources to estimate the energy consumption of data centres and telecommunication networks in the EU.
Strive	White paper	The Future of Data Centres: Navigating Energy Efficiency Policies in the EU and APAC	Link	This whitepaper discusses the increasing energy consumption of data centres and the stricter energy efficiency regulations being introduced in the EU and APAC regions.
Oeko-Institut e.V.	Techni cal report	Development of an Energy Efficiency Label for Data Centres	Link	It proposes an energy efficiency label for data centres, developed within the PeerDC project commissioned by the German Federal Environment Agency.
European Commission	Study	Synergies between Data Centres and Energy Systems	Link	The study aims to reconcile the increasing energy consumption of data centres with their critical role in European digital transformation. The study emphasizes utilising waste heat and water generated from data centre operations to support local energy systems, contributing to the EU's Green Deal and Digital Decade goals of achieving highly energy-efficient and climate-neutral data centres by 2030.
Data Centre Map	Database	Explore The Leading Global Data Centre Database	Link	The database is global, encompassing data centres worldwide, including those operated by data centre providers offering colocation, cloud, and connectivity services. It includes facilities ranging from hyperscale to edge data centres, spanning both smaller markets and major metropolitan areas. Listings are primarily submitted and maintained by operators, ensuring daily updates and continuous expansion with new data centres. The collected data provides access to a comprehensive research tool featuring industry-leading statistics and insights.

Uptime Institute	White paper	Tier Classification System	Link	Uptime Institute established the data centre Tier classification levels over 25 years ago, which continue to serve as the international standard for data centre performance. The Tier definitions outline the infrastructure requirements for data centre operations, with different classifications based on system availability needs. These classifications provide an objective and reliable method for comparing site infrastructure performance and aligning infrastructure investments with business objectives.
IEA-4E	Study	Energy efficiency of data centres	Link	Focus on improving energy efficiency by developing models, policies, and standards. It addresses challenges such as ICT energy consumption, lack of standardised metrics, and data limitations.
Climate Neutral Data Centre Pact	White paper	Climate Neutral Data Centre Pact presents new water metrics to European Commission	Link	The Climate Neutral Data Centre Pact (CNDCP) develops environmental metrics for data centres, recently proposing water conservation limits to the European Commission. It also works on monitoring, reporting, recycling, and energy efficiency to support climate neutrality.

2. Methodologies

a. Task 2 – Next steps towards a sustainable data centre sector

Aim and Objectives

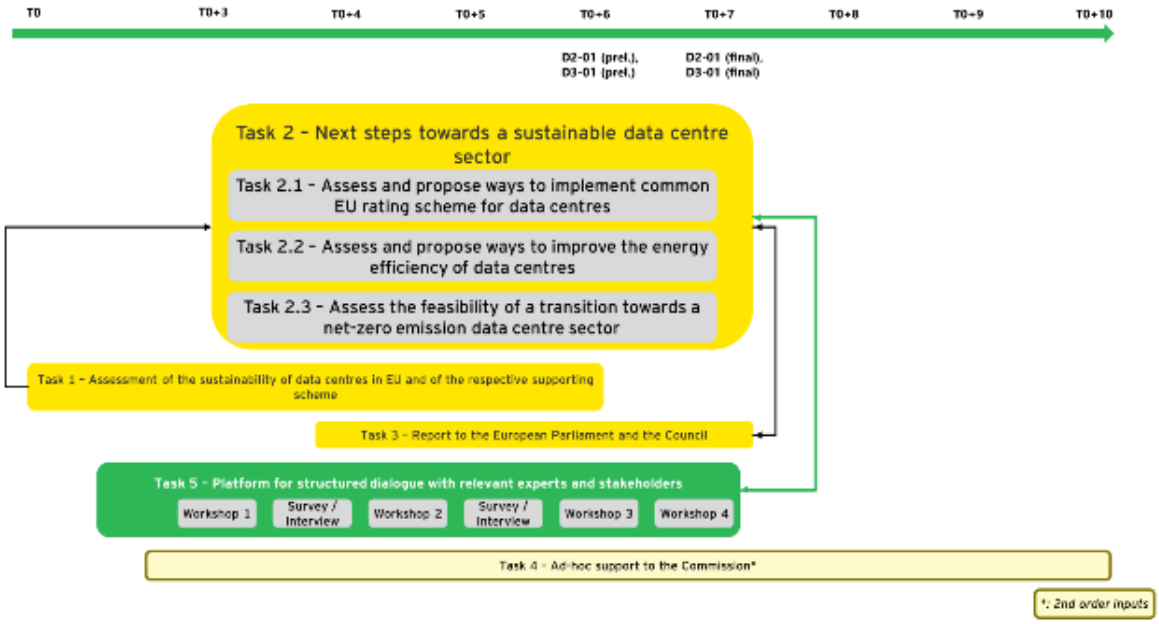
Task 2 aims to contribute to the development and implementation of effective measures that support the data centre sector's transition towards greater sustainability. This includes the possible creation of a common EU rating scheme, the establishment of minimum performance standards (MPS), and an assessment of the feasibility of achieving a net-zero emissions data centre sector. The task encompasses three objectives of the project as below with their corresponding sub-tasks:

Table 3 - Project objectives and corresponding sub-tasks

Project objectives	Sub-tasks
Evaluate the need for and identify the potential structure and components of a common EU rating scheme for data centres.	Task 2.1 - Assess the need and identify and propose ways to implement a possible common EU rating scheme for data centres
Assess technical measures to improve energy efficiency in data centres	Task 2.2 - Assess the need and identify and propose ways to improve energy efficiency of data centres, including establishing MPS
Develop MPS for energy efficiency	
Validate proposed measures and standards through expert consultation	
Assess the technical, economic, and regulatory feasibility of transitioning the data centre sector towards achieving net-zero emissions. This will involve exploring what such a transition entails, including defining key concepts and evaluating the implications for different types of data centres across the EU.	Task 2.3 - Assess the feasibility of a transition towards a net-zero emission data centre sector

The figure below provides an overview of the timeline and progress of the study, including the sub-tasks and the steps of the analysis, as well as the synergies with other tasks foreseen within this study.

Figure 1 - Overview of the timeline of Task 2



i. Task 2.1 – Assess the need and identify and propose ways to implement a possible common EU rating scheme for data centres

Led by **Borderstep** supported by AIT and EY

Desk research

The contractor conducted an exhaustive review of existing rating and labelling schemes for data centres, with a particular focus on those that align with climate emission reduction goals. This includes an analysis of international standards such as EN 50600 which provides a robust framework for assessing multiple criteria of sustainability aspects in a data centre maturity model. The desk research did also take into account all findings from the studies from the European Commission "Reporting requirements on the energy performance and sustainability of data centres for the Energy Efficiency Directive", conducted by COWI and Viegand Maagøe.[1]

Approaches that are currently under development such as PeerDC[2] have also been taken into account as well as the "Study on Greening Cloud Computing and Electronic Communications Services and Networks"[3], which looks at multiple indicators beyond carbon emissions and the goal of net-zero.

The contractor synthesised this information to identify gaps and opportunities for the proposed EU rating scheme, ensuring it prioritises climate-related impacts and the transition towards net-zero emissions.

The assessment methodology should rely on a practicable approach in line with Article 12(5) of Directive 2023/1791. For example, it should allow for consistent assessments of individual data

[1] https://op.europa.eu/en/publication-detail/-/publication/d9404897-7221-11ee-9220-01aa75ed71a1/language-en, https://op.europa.eu/en/publication-detail/-/publication/f6877423-98a2-11ee-b164-01aa75ed71a1/language-en/format-PDF/source-298395029 and https://op.europa.eu/en/publication-detail/-/publication/e5830a7b-98a5-11ee-b164-01aa75ed71a1/language-en/format-PDF/source-298397218

[2] https://peer-dc.de/label/

[3] https://digital-strategy.ec.europa.eu/en/library/study-greening-cloud-computing-and-electronic-communications-services-and-networks-towards-climate

centres as well as high-level assessments, e.g. at Member State or EU level, based on the data derived from reporting requirements of the current EED.

Stakeholder engagement

The contractor did integrate feedback from relevant stakeholders, obtained through online surveys and interviews, which have been conducted in conjunction with Task 1. This ensured a comprehensive understanding of the practical challenges and industry readiness for adopting a new EU-wide rating scheme. Additionally, the contractor organised a workshop to discuss the preliminary findings and refine the proposed rating scheme. The consultations and the workshop targeted a wide range of stakeholders, including industry representatives, Member State authorities, and experts familiar with EN 50600 and other relevant frameworks, to explore synergies with existing EU policies and standards, and how these can be adapted to focus more explicitly on reducing greenhouse gas emissions.

An updated draft of a rating scheme designed as a multi-criteria label (see chapter 3.a.iii) was updated to reflect stakeholder feedback received at different workshops, various interviews and extensively in written form. Since the first draft, multiple sections have been refined.

ii. Task 2.2 – Assess the need and identify and propose ways to improve the energy efficiency of data centres, including establishing minimum performance standards

Led by **AIT**, supported by Borderstep and EY.

> The scope of the data collection and assessment focused on the first reporting period as delineated under Article 12 of the EED Recast and the Delegated Regulation 2024/1364, for which the reporting took place by May 15, 2024, and September 15, 2024, respectively, thus, covering data up to 2023. Inputs received until April 24, 2025 were considered for the development of the Minimum Performance Standards (MPS).

The methodology of Task 2.2 followed a multi-step, evidence-based process that integrated regulatory analysis, stakeholder engagement, and performance data evaluation to develop realistic minimum performance standards (MPS) for energy efficiency in data centres. For this work, data and feedback received until April 24, 2025 were considered. The approach included the following components:.

Review of external standards, policies and initiatives

- An extensive desk study was conducted to collect and compare existing regulations, voluntary initiatives and guidelines related to data centre sustainability. Sources included (see Table 4): the German “Energieeffizienzgesetz”[4] (German Energy Efficiency Act), Directive GB 40879-2021 (China), the Climate Neutral Data Centre Pact (CNDCP), UNEP’s Green Public Procurement Guideline, Blauer Engel (Blue Angel) label (Germany) and more. From these, commonly proposed Key Performance Indicators (KPIs) such as PUE, WUE, REF, and ERF were identified, along with suggested values and deadlines. Further indicators, such as the Carbon Emission Rate (CER), Carbon Usage Effectiveness (CUE) or IT Equipment Utilization for Server Virtualization (ITEUsv) are not within the current scope of the study, as they cannot be assessed based on the reported data and were also considered less important in the stakeholder survey (see Annex 1).

[4] Energieeffizienzgesetz vom 13. November 2023 (BGBl. 2023 I Nr. 309)

Table 4 - Other directives, initiatives, guidelines, projects and labels and KPIs they address

Directive/initiative/guideline/project/label	PUE	WUE	REF	ERF	CER	CUE	ITEUsv
German Energy Efficiency Act (Germany)	x		x	x			
Directive GB 40879-2021 (China)	x						
Climate Neutral Data Centre Pact (EUDCA)	x	x	x	x			
Noord-Holland initiative (Netherlands)	x						
Green Public Procurement Guideline (UNEP: U4E)	x	x	x	x	x		
Guide to Environmental Sustainability Metrics (Schneider Electric)	x	x	x			x	
Project DC-CFA (Singapore)	x						
Blauer Engel (Germany)	x		x	x	x		x

Analysis of reported data

Real-world data from 748 data centres across the EU was analysed based on submissions under Article 12(5) of the Energy Efficiency Directive. All data received by 24 April 2025 was included. After preprocessing and evaluation to calculate PUE, WUE, REF and ERF, about 600 entries remained, depending on the KPI. These indicators were then calculated individually for each data centre.

Statistical evaluations were conducted to assess the distribution and variance of these indicators, taking into account:

- Geographic factors, using Cooling Degree Days (CDD) as a proxy for climate,
- Operational characteristics such as data centre size, type and year of commissioning.

To define feasible and, where necessary, differentiated thresholds, both the median and the energy-weighted average (using total energy consumption as the weighting factor[5]) were calculated for each indicator.

Stakeholder consultations and surveys

To ensure the practical relevance and sectoral applicability of the evaluation, insights from interviews with experts, stakeholder surveys and workshops were systematically integrated into the process. The organisation of the survey was split into two phases, and in total 148 responses were collected, with 123 validated for inclusion in the analysis.The consultation activities aimed to identify priority areas, preferred indicators and key influencing factors for sustainability in data centres. Focus areas included energy efficiency, water consumption, renewable energy use and waste management. In addition, qualitative inputs on regulatory expectations, market dynamics and internal sustainability strategies informed the contextual framing of performance indicators and policy scenarios.

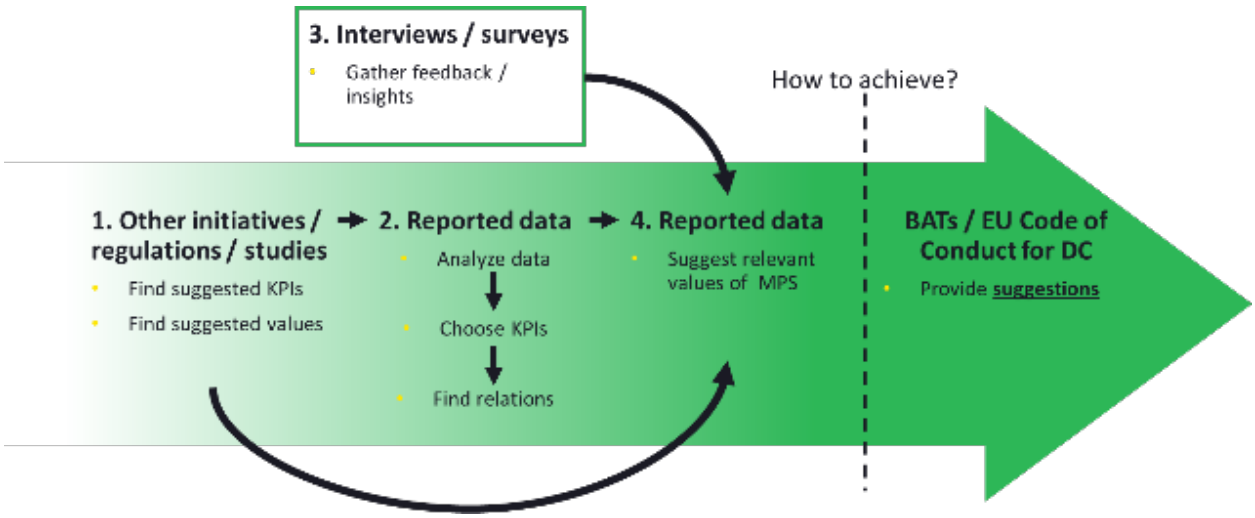
Formulation of proposed MPS based on combined evidence

The proposed MPS thresholds were developed through a triangulated methodology, integrating evidence from external regulatory and voluntary frameworks, statistical analysis of reported data and stakeholder input. As illustrated in Figure 2, the process began with the review of other initiatives, regulations and studies to identify commonly suggested KPIs and reference values. In a second step, real-world data reported by data centres under Article 12(5) of the EED was analysed to extract

[5] Annex IV of Commission Delegated Regulation (EU) 2024/1364

relevant indicators, define relationships and select key metrics. This was complemented by stakeholder insights gathered through interviews and surveys, ensuring that the proposed thresholds reflect both technical feasibility and sectoral readiness.

Figure 2 – Logic of MPS proposition



The proposed MPS thresholds were designed with the objective of being directly derivable from the existing EU-wide reporting obligations under Article 12 of the Energy Efficiency Directive. They take into account the differences between new and existing data centres, the type and availability of reporting data, and the specific characteristics of each indicator. A distinction is made between design values, which are relevant before and during construction, and operational values, which become meaningful only after a certain operational period.

This approach ensures that the MPS are ambitious but grounded and that their implementation pathways are aligned with both the EU policy goals and the technical realities of diverse data centre contexts.

Integration of BATs and Feasibility Assessment

As part of Task 2.2, a comprehensive BAT (Best Available Technologies) catalogue was compiled and assessed to identify effective measures for improving the assessed KPIs: PUE, WUE, REF and ERF. The identified measures were grouped by indicator:

- **PUE**: 23 measures
- **WUE**: 6 measures
- **REF**: 14 measures
- **ERF**: separated into 5 suitable heat sources within the data centre and 19 on suitable heat sinks

To evaluate and prioritise the most relevant BATs, a scoring system (see Table 6) was developed. It combined qualitative impact ratings for each KPI (scale from **-5 to +5**, allowing for negative effects) with implementation-related criteria rated on a **1 to 5 scale**. The total score for each measure was calculated using the following weighted criteria:

Table 5 - Scoring system for BATs

Criterion	Scale	Weight
Influence on KPIs		

Contribution to PUE improvement	-5 to +5	20%
Contribution to WUE improvement	-5 to +5	10%
Contribution to ERF improvement	-5 to +5	10%
Contribution to REF improvement	-5 to +5	10%
Further parameters		
Technical maturity level (TRL)	1 to 5	10%
Payback time	1 to 5	15%
Organizational effort	1 to 5	5%
Implementation time	1 to 5	5%
Energy savings potential	1 to 5	10%
Risk and operational impact	1 to 5	5%

This rating scheme ensured that measures with strong impact on PUE (the most widely used and reported KPI) were prioritized, while also recognizing trade-offs, implementation barriers and synergies with other sustainability indicators.

To test the applicability of BATs under realistic conditions, 27 data centre archetypes were defined based on median values of the reported data, considering only valid data points and a ramp-up period of 3 years (excluding data centres built after 2023). A distribution of the energy used within the data centre was considered in the fields of cooling, UPS, ventilation IT and others (e.g. lighting).[6] The factors influencing the archetypes can be found in the table below.

Table 6 - Considered factors for the archetypes

Age	# of data centres	CDD	# of data centres	Size in MW	# of data centres
Old (<2013)	264	Low CDD (<12)	49	Very small – small (< 1 MW)	143
Average (2013-2018)	95	Medium CDD (≥ 12 and <165)	301	Medium – large (≥ 1 MW and <10 MW)	250
New (2019-2021)[7]	70	High CDD (≥165)	79	Very Large (≥10 MW)	36

More information on the archetypes can be found in Annex 3.

Across the 27 data centre archetypes, existing system configurations for cooling, power supply, ventilation and lighting were selected illustratively according to a combination of climate zone, facility

[6] Christine Kulemann, Philipp Husi, René Gürber, Andrea Grüniger, Stefan Gemperle: Waste Heat Utilization of Data Centres – Potential Study and Recommendations for Operators and Municipalities. Final report commissioned by EnergieSchweiz, Swiss Federal Office of Energy (SFOE), June 1, 2023

[7] Considering a 3-year ramp-up period, only data centres with an operation entry up to 2021 were included in the analysis; sites commissioned in 2022 or later were excluded

age, data centre size and IT equipment density[8,9,10]. For newly-built large and medium-sized data centres in high- and medium-CDD (Cooling Degree Days) regions, advanced solutions such as rear door heat exchangers, in-row cooling or direct liquid/immersion cooling were assumed to be applied to efficiently manage high heat densities generated by blade or high-density servers. These systems would allow targeted heat removal close to the source, reducing overall cooling energy demand.

In contrast, small new data centres were assumed to rely on efficient CRAH (computer room air handler) systems, which offer a balance between capital cost and performance for moderate loads. High-efficiency modular uninterruptible power supply (UPS) systems were assumed to be implemented in new builds, offering scalability and better partial load efficiency. Ventilation in new centres was assumed to be supported by liquid-assisted or highly efficient air handling units to optimise air distribution and reduce fan energy consumption. Lighting was assumed to be designed using smart LED systems and automation (e.g. occupancy sensors) to minimise non-IT power consumption.

In average-aged facilities, typically built with medium-density rack servers, less advanced but still improved systems were assumed to be used. CRAH and chilled water loop systems dominate the cooling configurations, offering reasonable performance in combination with ducted ventilation systems with basic control. Power was assumed to be supported by improved UPS solutions, often modular but not state-of-the-art. Lighting systems ware assumed to rely on LED with motion detection rather than fully integrated smart automation.

Older data centres, particularly in low- and medium-CDD regions, were assumed to be equipped with legacy systems such as CRAC (Computer Room Air Conditioner) units or basic CRAH systems with external chillers. Cooling systems were assumed to be less localised and less efficient, and the servers were assumed to be a mix of legacy workloads (web, HPC, data) which vary in heat profile. Double-conversion UPS systems were assumed to be common in these setups, reflecting older design standards. Ventilation was assumed to be handled via ducted systems with variable-speed fans and lighting was assumed to be mostly fluorescent or basic LED, often without automation. These configurations were assumed to be more energy-intensive and less adaptable to modern load profiles.

Overall, the selection of systems across the archetypes reflects a progression from legacy infrastructure to best available technology (BAT) depending on age, climate conditions and IT density, providing an indicative picture of the diversity in the European data centre landscape.

The most promising BATs were tested in these archetypes to evaluate their potential to improve the KPIs.

Annexes 2 and 3 provide the full BAT catalogue, evaluation methodology, archetypes and scoring matrices.

iii. Task 2.3 – Assess the feasibility of a transition towards a net-zero emission data centre sector

Led by **Borderstep**, supported by AIT and EY.

Comprehensive feasibility study

[8] Pelda Johannes, Reuter Stefan, Cozzini Marco, Gebetsroither-Geringer Ernst, Salaymeh Abdulraheem, Paradiso Rosanna, Holler Stefan (2023): Advanced algorithm for spatial identification, evaluation of temporal availability and economic assessment of waste heat sources and their local representation. IEA DHC/CHP Report, 2023.

[9] https://www.sciencedirect.com/science/article/pii/S0140700724000458

[10] Kulemann, C., Husi, P., Gürber, R., Grüniger, A., & Gemperle, S. (n.d.). Abwärmenutzung von Rechenzentren – Potenzialstudie und Empfehlungen für Betreiber und Gemeinden.

The contractor assessed the practicality of transitioning the data centre sector towards net-zero emissions. This involved analysing the current state of the sector based on Task 1 results, potential technological advancements, and the economic and regulatory requirements necessary for this transition. The study also considers how existing standards like EN 50600 can be leveraged or modified to support this transition.

Compatibility with existing frameworks and goals

The contractor evaluated how the proposed net-zero transition strategies can be integrated with existing EU frameworks, including the RED, EED, EPBD, the Taxonomy Regulation, and other relevant policies. The focus will be on ensuring that these strategies are realistic, enforceable, and aligned with current legislative goals, while maintaining compatibility with goals of the digital decade.

Stakeholder engagement

The contractor engaged with stakeholders through workshops and additional consultations, by providing questions to the online survey and interviews with experts which are described in the report on Task 1. This engagement focussed on gathering input on the practical challenges and opportunities associated with the transition to net-zero emissions, ensuring that the proposed strategies are feasible and supported by the industry and regulators.

3. Study developments and results

a. Task 2.1 – Assess the need and identify and propose ways to implement a possible common EU rating scheme for data centres

i. Need for a common EU rating scheme for data centres and possible types

As digitalisation progresses, the importance of data centres is increasing worldwide. Indeed, they are central infrastructures for cloud services, social media, artificial intelligence, streaming services and many other digital applications. However, this is accompanied by a drastic increase in energy requirements, which is increasingly becoming the focus of the climate debate. According to the International Energy Agency (IEA), data centres consume approximately 415 TWh electricity per year, constituting approximately 1.5 percent of the world's total electricity consumption.[11] Projections indicate that this proportion will continue to increase in the forthcoming years towards 945 TWh (base scenario), primarily due to the substantial growth of energy-intensive accelerated computing which is used mainly for AI purposes. For the EU a current meta-sutdy assume that data centres in 2022 consumed 45-65 TWh[12]. An earlier study expected, the energy demand of data centres in the EU will grow towards 98.5 TWh in 2030, representing around 3.2% of the EU final electricity demand[13]. The report from the International Energy Agency mentioned above estimates the current (2024) energy use of data centres in the EU at 70 TWh/a and expect it to rise by 45 TWh until 2030 towards 115 TWh[11].

Considering newly built (e.g. AI) data centres, current project announcements and other recent studies, it is likely that this prediction will be accurate or even exceeded; a lower development is unlikely. This is not merely an issue of electricity consumption; data centres also have a substantial indirect environmental impact. For instance, CO_2 emissions resulting from non-renewable electricity sources, or the substantial utilisation of water for cooling purposes, are notable contributors to this impact. As reported by various media outlets, data centres of a single provider in the US state of Oregon utilised approximately one billion litres of water (355 gallons in the source) in 2021 for the purpose of server cooling[14].

Moreover, the lifecycle of data centres is associated with the use of valuable raw materials and a considerable amount of electronic waste. The carbon footprint of a data centre is therefore contingent not only on the energy source utilised, but also on the design of the facility, the expected service life of the hardware, and the efficiency with which resources are utilised. In view of the ambitious climate targets being pursued by various countries, including the EU's objective of achieving climate neutral data centres by 2030 are therefore increasingly becoming a focal point for politicians and the public.[15]

Nevertheless, a fundamental challenge in the sustainable regulation and evaluation of data centres pertains to the **absence of actual consumption data in the public discourse**. A significant number of operators, both small in-house data centres, but also many prominent international cloud providers refrain from disclosing comprehensive data concerning the energy consumption of their individual data centres or the precise origin of the electricity utilised. Instead, the focus is often on providing global averages or voluntary sustainability reports, which, due to their nature, lack credibility and can be challenging to verify.

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[11] Base year 2024, source https://www.iea.org/reports/energy-and-ai/energy-demand-from-ai

[12] Kamiya, G., & Bertoldi, P. (2024). *Energy Consumption in Data Centres and Broadband Communication Networks in the EU*. https://interactdc.com/static/images/documents/JRC135926_01.pdf

[13] https://digital-strategy.ec.europa.eu/en/library/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market

[14] https://www.oregonlive.com/silicon-forest/2022/12/googles-water-use-is-soaring-in-the-dalles-records-show-with-two-more-data-centers-to-come.html

[15] https://commission.europa.eu/document/download/84c05739-547a-4b86-9564-76e834dc7a49_en?filename=communication-shaping-europes-digital-future-feb2020_en.pdf

This lack of transparency has several consequences. Firstly, the absence of reliable data precludes states from developing effective policies to promote energy efficiency. Secondly, there is a risk of greenwashing for operators by making unsubtantiated or misleading claims about the environmental value of their services. Thirdly, it reduces the incentive for more ambitious companies to differentiate themselves from their competitors by implementing sustainable IT infrastructures, since these additional efforts can hardly be made visible and comparable for customers and investors. An existing report by Viegand Maagøe and COWI describes the existing approaches of data centre sustainability assessment schemes and already presents some options for data centre labelling and MPS.[16]

ii. Concept of a rating scheme

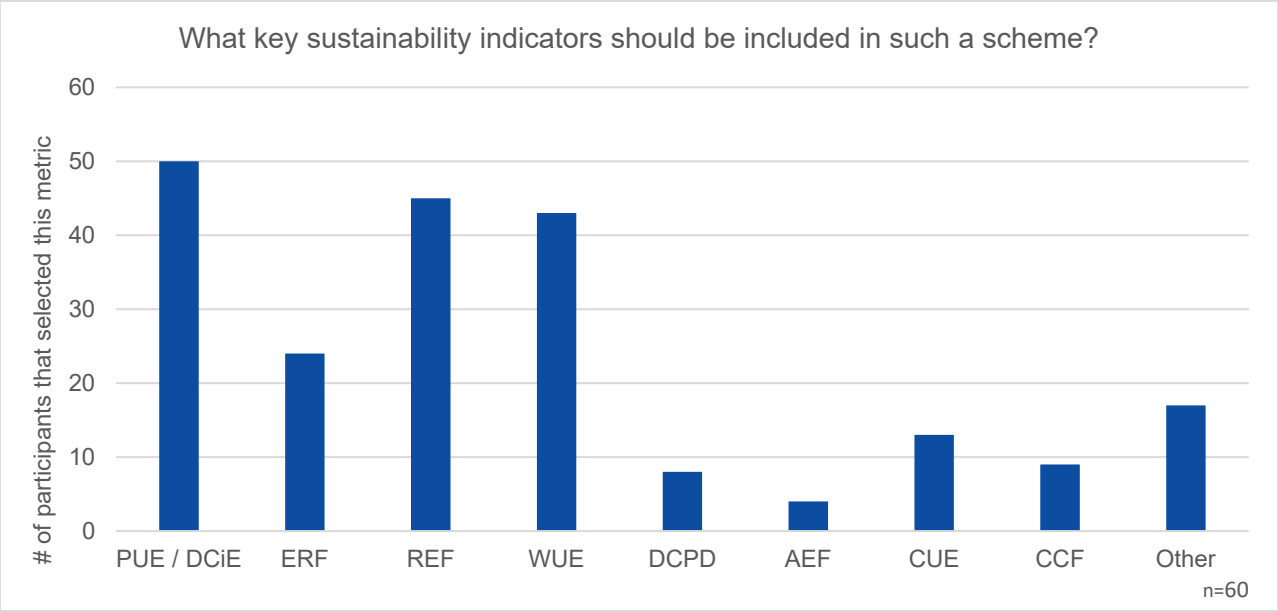
In the ongoing discourse on the environmental sustainability of data centres, there have been endeavours to quantify their environmental impact using a **singular metric**, such as energy consumption per computing unit or CO_2 emissions per year. While such mono-dimensional approaches may appear to be a practical solution at first glance, they ultimately prove to be inadequate. Data centres are complex infrastructures whose environmental sustainability is influenced by a variety of factors. These include energy efficiency and the electricity mix, as well as cooling technology, space utilisation, hardware life cycles and recycling practices. A solitary pivotal figure is incapable of adequately addressing this heterogeneity, nor can it provide a robust foundation for political decisions, investment decisions, or customer orientation.

Furthermore, there is a possibility of misinterpretation or deliberate simplification when examining individual key figures in isolation. For instance, a low PUE (Power Usage Effectiveness), defined as the ratio of total power consumption to IT power consumption, is indicative of high energy efficiency. However, it should be noted that a high PUE does not provide any indication of whether the electricity is derived from fossil fuels, the duration of server utilisation, or the extent to which waste heat is reused. A data centre with an excellent PUE that is operated with electricity deriving from coal-fired power plants can have a worse carbon footprint than a slightly less efficient site that only uses green electricity and supplies local buildings with waste heat.

Consequently, it is logical to evaluate sustainability not in a simplistic manner, but by employing a **multifaceted set of criteria**. It is recommended that established and internationally recognised indicators be utilised, with each indicator capturing a distinct aspect of sustainability. In the first survey, stakeholders were asked, what indicators should be used for a rating scheme for data centres (multiple options were possible as well as an option to enter alternative indicators). The results are presented in chapter iii.

[16] https://op.europa.eu/en/publication-detail/-/publication/f6877423-98a2-11ee-b164-01aa75ed71a1

Figure 3 – Survey results – Key sustainability indicators



A strong preference was on the Power Usage Effectiveness (PUE; Data Centre infrastructure Efficiency - DCiE is just the reciprocal value and thus not considered as alternative indicator). The Renewable Energy Factor (REF), the Water Usage Effectiveness (WUE) and the Energy Reuse Factor (ERF) were also seen by many stakeholders as most relevant metrics and thus will be used later.

In the forefront to this study, there was already a discourse on the use of different metrics, whether these could be merged into a common metric by weighting them, as proposed for example by the Öko-Institut.[17] During this study, implementing such a combined metric has been considered. However, it brings the danger of neglecting important factors. For example, it is hard to weigh reused heat against water consumption of a data centre or green power procurement against energy efficiency. There might be local reasons, why heat reuse capacities are limited (especially for legacy data centres) which could lead to a disadvantage – especially for those in hotter climate. A combined metric makes it hard to understand why a data centre got a bad rating, even if it makes great efforts in the area of green energy purchasing and energy efficiency. It was therefore decided to report the indicators separately.

To guarantee the comprehensibility of this variety of data, it is imperative to present the key figures in a clear and standardised manner. One possible approach to this would be to employ the use of a multi-criteria sustainability label, including an easy to comprehend colour pattern (e.g. traffic light colours) for important indicators. This enables especially operators and professional customers to swiftly ascertain the performance of a data centre across various metrics and choose an operator by the individual sustainability strategy. The implementation of such a label would generate heightened transparency, foster innovation, and establish equitable competitive conditions for sustainable providers.

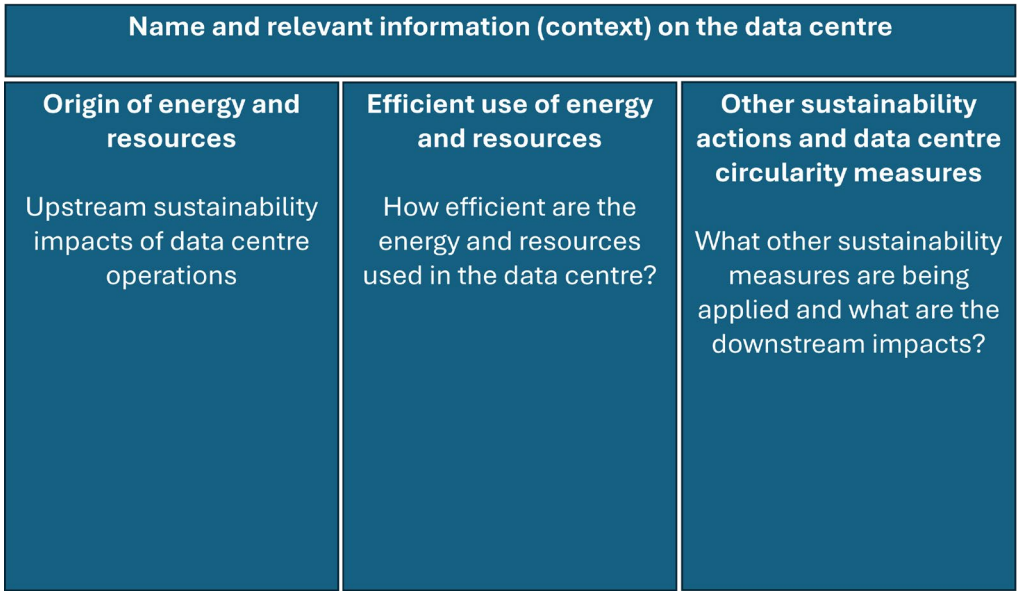
Taking into account the desk research results and the immediate stakeholder feedback in the surveys, a first draft of such a label was generated. It consists of four sections:

- On top, the general information on the data centre provides important context to better interpret the sustainability metrics.

[17] https://www.oeko.de/fileadmin/oekodoc/Oeko-Institut_energy-efficiency-label-for-data-centres.pdf

- The left-hand side is intended to make upstream environmental impacts easier to understand by providing information on where electricity and resources such as water come from and how they are produced.
- The central field shows the efficiency achieved in the data centre building, its infrastructure and how efficiently the IT hardware is operated.
- The right-hand side is aimed at downstream aspects, circularity and other sustainability measures.

Figure 4 - General concept of the data centre sustainability label



To minimise the burden to data centres, the label is based on key figures that are already used for EU reporting. Other environmental indicators such as the cooling degree days (which were reported incorrectly in many cases) could be automatically extracted from Eurostat based on the location.[18] Similarly, local water depletion can be obtained, for example, from the freely available geodata from Aqueduct of the World Resources Institute.[19]

The most fundamental key performance indicators, such as the share of renewable energy, the Power Usage Effectiveness (PUE) and the Water Usage Effectiveness (WUE), are displayed graphically and are easy to interpret using colour coding (green-yellow-orange-red). The other sustainability indicators and measures on the right-hand side are given green icons, making the label greener overall if many measures have been implemented.

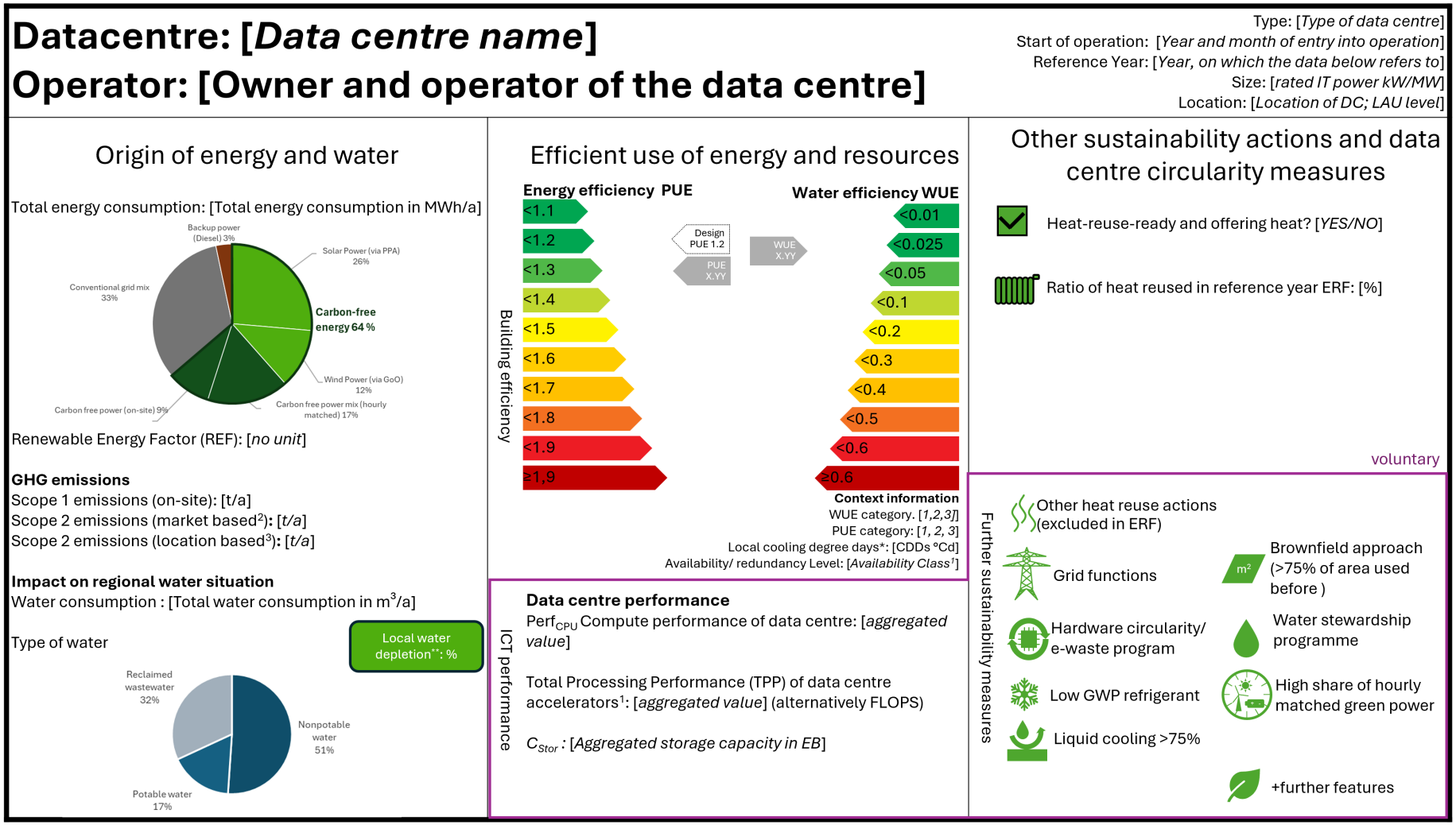
As some metrics are still difficult to collect today (especially the performance metrics around colocation data centres), these should be provided as voluntary metrics.

iii. A rating scheme in the form of a label

A proposal for the label is shown on the next page and further details on the containing elements will be provided in the following pages.

[18] https://ec.europa.eu/eurostat/cache/metadata/en/nrg_chdd_esms.htm
[19] https://www.wri.org/aqueduct

Figure 5 - The suggested rating scheme for sustainability in data centres in the form of a multi-indicator label



PPA: Power purchase agreement
GoO: Guarantees of origin

*Automatically filled by Eurostat data **automatically filled with data from Eurostat or WRI Aqueduct data
[1]Perf CPU as defined by EN 303 470 Section 5.2
[2]Scope 2 emissions calculated with the power mix a data centre purchases (PPA, GoO, on-site etc.)
[3]Scope 2 emissions calculated with the average grid mix of the country the
[4]Availability Class according to EN50600 (alternatively ISO/IEC 22237

The relevance and significance of the individual elements are analysed in more detail for each segment below.

The head element

Figure 6 - The header element with the most important context information



The header element contains the **name** of the data centre and the **operator** to uniquely identify the object. The header element also contains the **type** of data centre (extracted from DATACENTRETYPE of the EU database), which can provide information on the operator model. As in the previous database, it is also possible to combine these. The following types have been used so far:

- CO_HOSTING_DATA_CENTRE_SINGLE_STRUCTURE
- CO_HOSTING_DATA_CENTRE_SINGLE_STRUCTURE_WITH_COLOCATION_SERVICES
- CO_HOSTING_DATA_CENTRE_GROUP_OF_STRUCTURES_WITH_COLOCATION_SERVICES
- COLOCATION_DATA_CENTRE_SINGLE_STRUCTURE_WITH_CO_HOSTING_SERVICES
- COLOCATION_DATA_CENTRE_SINGLE_STRUCTURE
- COLOCATION_DATA_CENTRE_GROUP_OF_STRUCTURES
- ENTERPRISE_DATA_CENTRE_GROUP_OF_STRUCTURES
- ENTERPRISE_DATA_CENTRE_SINGLE_STRUCTURE

Start of operation indicates the year and month in which operation of the data centre commenced. This is particularly important as some data centres achieve poorer KPIs in the first few years due to low utilisation, even though they are technically highly optimised (problem of partial load regarding the efficiency of servers, cooling infrastructure, power converters, etc.).

The **reference year** indicates the period to which the data specified here refers to recognise how up to date the label is (it is suggested that this be updated annually with the reporting scheme to allow for the dynamic change of data centres in the first few years).

Furthermore, the **size** of the data centre is specified in kW or MW, which helps to classify the data centre in terms of size class, whether it has a rated power of a few hundred kW, single-digit MW, double-digit MW (hyperscale) or even higher (modern hyperscale and special AI data centres). This also has a significant impact on energy efficiency in data centres and often also on other metrics such as waste heat utilisation, as such large amounts of heat can rarely be absorbed in one place.

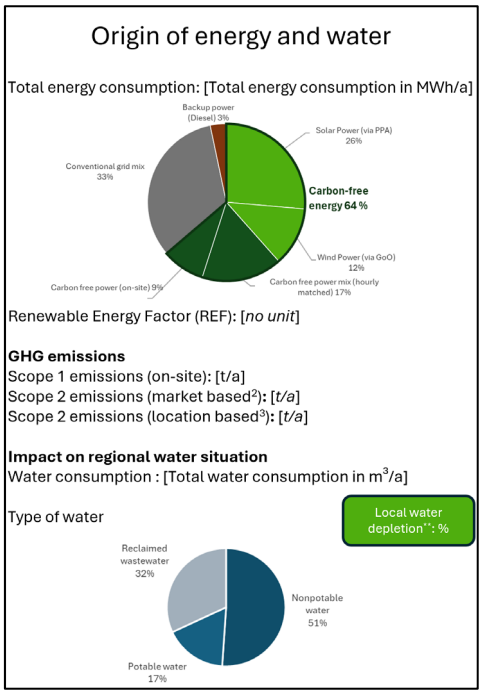
The **location** of the data centre is specified at LAU level.[20] This means that the exact location is not disclosed (which may be security-relevant), but information is still provided, so that the local context of water consumption or cooling efficiency can always be better categorised in the context of ambient conditions (temperature, humidity).

The left side element on the origin of energy and resources

[20] https://ec.europa.eu/eurostat/web/nuts/local-administrative-units

The left segment gives an overview of the actual (upstream) impact of energy or resource consumption. As climate change is one of the key priorities regarding impacts of data centre sustainability and the EU Commission has set targets regarding data centres to become climate neutral by 2030, a strong focus lies on energy which is a key factor for greenhouse gas emissions.

Figure 7 - The left segment of the label with information of upstream impacts



At the top, the **total energy consumption** in MWh should be provided with two significant figures.

Below, a **pie chart shows the origin of the data centre energy**, differentiating between high quality green power certificates (with hourly matching and onsite renewable power). Green PPAs still guarantee a direct investment in renewable power, but neglect the fact, that wind and solar power alone are depending on the availability of these resources and thus are not sufficient to fully decarbonize the power sector system wide.[21] Guarantees of origin have also been objected to increasing criticism and doubt on their credibility is rising.[22] Accordingly, green electricity, which can verify hourly that it was generated at the same time as it was consumed, and on-site electricity are shown as darker green. A green line around all carbon free power segments provides a quick insight into the share of carbon-free power.

Conventional electricity generation is shown as a grey segment in the pie chart. Electricity from back-up diesel generation is shown in orange. If back-up power is generated from CO_2-neutral energy sources (e.g. renewable H_2, HVO[23]), it can also be shown in dark green and be added to the carbon free part. If a data centre receives district cooling based on renewable power, the indirectly purchased green power used for district cooling should also be visualized as separate (light green) piece in the pie chart.

Below the pie chart, some KPIs are presented:

- The renewable energy factor – REF

[21] https://www.wri.org/insights/247-carbon-free-energy-progress
[22] https://sustainable-energy-week.ec.europa.eu/news/corporate-renewable-procurement-greenwashing-or-key-driver-eus-clean-industrial-deal-2025-02-06_en
[23] Hydrotreated vegetable oil (HVO) is a biofuel made by the hydrocracking or hydrogenation of vegetable oil.

- The GHG emissions for scope 1 emissions and scope 2 emissions (location and market based)

While Scope 1 is of high importance to present the actual GHG emissions that happen on site, both scope 2 allocation methods (location based and market based) are relevant to assess the impacts of a data centre.

The amount and origin of the water consumption is shown at the bottom. Here, the first point is the total water consumption in m³ per year. Also, the local water depletion is shown as a button on the right. Depending on the local water depletion, this button has a different colour:

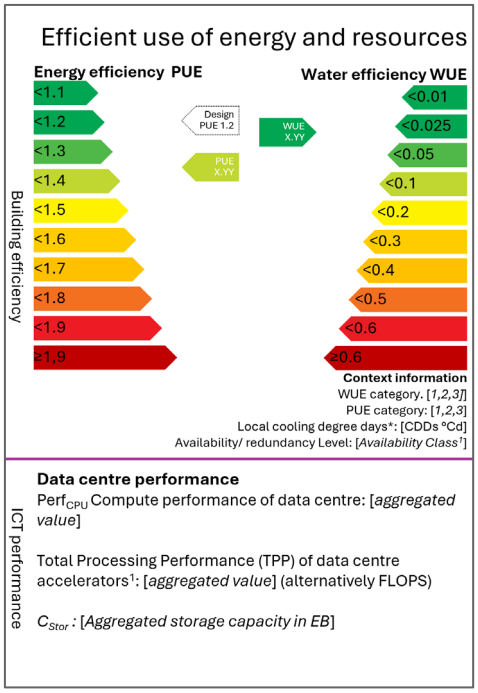
- <25% depletion: green
- 25-50% depletion: yellow
- >50% depletion: red

The shares of different **types of water** that are consumed are then presented as pie chart with different blue colours, at least divived between potable and non-potable water. If an operator wants to express their effort towards more sustainable low-risk water sources (e.g. rainwater, shipping canal, groundwater, lake/sea/river water...) they can voluntarily add the share of these sources.

The central segment on the efficient use of energy and resources

The central element represents the efficiency of the processes that happen on site of the data centre, the building, the infrastructure and partially also in the IT equipment/software. It is divided into building efficiency on the top and ICT performance at the bottom. It is suggested that the ICT performance metrics will be provided voluntarily, as it takes some effort to collect them and there is a large uncertainty regarding the results. Colocation providers also struggle to collect them, as they usually don't know the exact technical specifications of their customers hardware.

Figure 8 - The central segment of the data centre sustainability label



The first part of the efficiency section consists of the Power Usage Effectiveness (PUE), which is defined as:

$$PUE = \frac{E_{DC}}{E_{IT}}$$

with E_{DC} (*Total energy consumption*) and E_{IT} (*Total energy consumption of information technology equipment*), both defined in the current reporting scheme.[24] This metric is relevant, because it puts the total energy (IT energy + infrastructure/building energy) in relation to the IT energy use and thus can be used to describe the efficiency of cooling/ventilation, power supply/UPS and other supporting infrastructures.

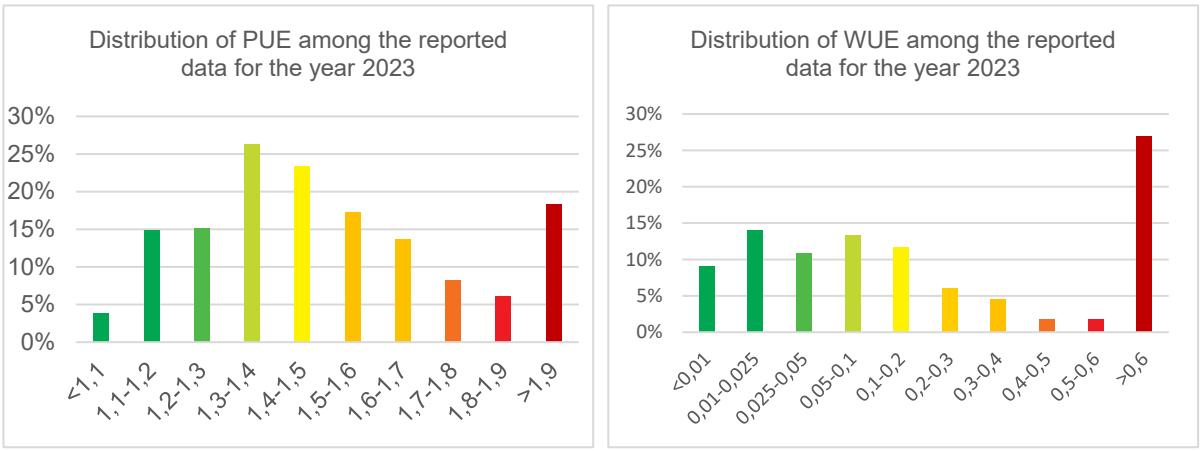
The building efficiency also includes the Water Usage Effectiveness (WUE), which is defined as:

$$WUE = \frac{W_{IN}}{E_{IT}}$$

with W_{IN} (*Total water input* into the data centre), also defined in the reporting scheme[24]. This metric is important, as it describes the water consumption per IT energy use, which is a useful indicator to assess the amount of water consumed independently of the size of the data centre (by dividing by IT energy use).

Both PUE and WUE are displayed on a colour scale, which shows the performance of the data centre regarding to this indicator using an internationally easy-to-understand logic (traffic light colours red-yellow-green). The scales were selected based on the figures from the data that was reported under the EED so that a good distribution of the existing data centres across the scale is possible. The scale is more complex to establish for the WUE, as the values are very diverse. To better differentiate between the most efficient data centres, the lower part of the scale is non-linear, but divided into smaller segments. The scales were adjusted during the development process based on feedback from stakeholders; some of the first drafts still had different scale divisions/colours.

Figure 9 and 10 - The distribution of existing data centres on the proposed efficiency scales in the label



In the middle, between PUE and WUE scales are the pointers, that show the values for the respective data centre. The pointer is coloured in the according value of the scale. For new data centres up until their third year of operation, the design PUE can be shown in a white pointer with dotted border, to better reflect that new data centres have disadvantages of ramping up utilisation.

Since the use of water-intensive evaporative cooling is a very effective measure for reducing energy consumption, there is a well-known conflict of objectives between water consumption and energy consumption. In many regions of the EU, water is not a scarce resource (water depletion <25%),

[24] In Annex II of the Commission delegated regulation (EU) 2024/1364 of 14 March 2024

and if the source is carefully selected (e.g. seawater, river water, rainwater, etc.), water consumption also has no relevant impact on the water supply of the local population and environment. Therefore, in cases of very low water depletion and no additional risk from the data centre (water consumption compared to available resources e.g. <5%), it could be considered to use a neutral scale (e.g. only green tones) for the WUE or to adjust the numbers at the scale. Otherwise, there is a risk that evaporative cooling as an energy efficiency technology will be penalised too broadly due to its water demand.

On the bottom part of the label, **performance metrics** are displayed. As previously described, it is suggested that these metrics are presented voluntarily. These performance metrics are only useful in combination with the total power value on the left segment, to form a quotient of performance/energy or performance/water. If these values are removed from the label for any reason (e.g. business secret), the metrics would not be useful anymore and should be replaced with calculated efficiency metrics (e.g. SERT 2).

The **$Perf_{CPU}$** value aggregates the performance of all servers in a data centre and therefore is a good indicator to verify or falsify claims made by data centre operators in their communications regarding their facility's ability to provide more compute per unit of energy or carbon. .

Still, it is almost impossible to provide a metric that represents performance for all workload types, as different software/workloads need very different server resources (e.g. memory intense applications, I/O intense applications, some applications need high single core performance, others run highly distributed, etc.). However, there are benchmark tools (e.g. SPEC SERT2 suite) to measure multiple values of different benchmarks in servers and combine them to get a sufficiently good result to compare servers for general purpose applications. For new servers, the Ecodesign regulation for servers and storage products describes in Annex III a methodology to calculate an active state efficiency and for new servers.[25,26] It can be expected that this value can be derived from specifications provided by the manufacturer but still, this is only useful for the operator of the server itself and not necessarily for the building operator (e.g. colocation data centre).

The Green Grid suggests that values for this metric can be derived from data bases which reflect on measured values for specific server generations, and a value can be picked by entering basic data of the server (CPU SKU, cores, …).[27] Even though this can lead to some additional deviations, this methodology seems to be a good compromise between the effort of getting data and a precision of such performance numbers, which are anyway not representative for all workloads (as described above). Therefore, this approach represents a pragmatic and adequate solution to a complex problem.

Still this metric is only representative for general purpose servers. It neglects in many cases the performance of specific accelerators, which are used for example for AI workloads (both training and inference) currently growing extremely fast. For this purpose, the introduction of a new metric, Total Processing Performance (TPP), is proposed. While the FLOPs (Floating Point Operations per Second) metric has become established in supercomputers in recent decades to compare computing power, it is decreasingly suitable for describing the computing power of special AI accelerators, because these are often not designed for floating point operations, but for a lower 4-, 8- or 16-bit precision (and extremely large parallel matrix operations). The Total Processing Performance measures the operations per second at any precision and then multiplies it with the according number of bits at which these operations per second were reached. FLOPS are therefore simply multiplied by 32, while the operations at 16-bit precision are multiplied by 16. Although this is only a rough approximation, it is more suitable than relying purely on FLOPs. TPPs are already used in the regulation of export restrictions for high performance chips from the USA or UK. If a chip can perform

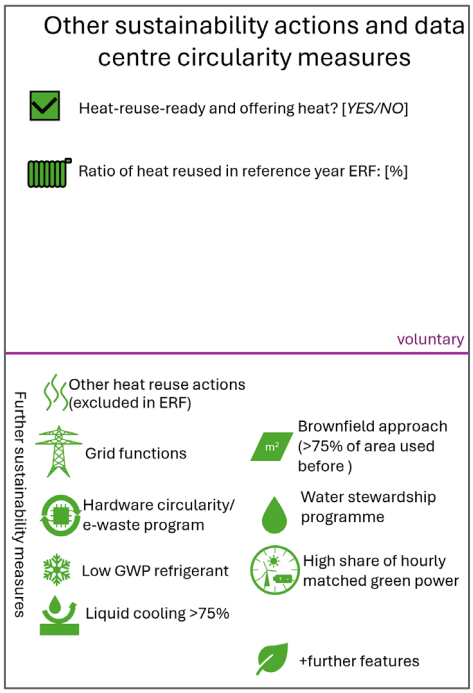
[25] COMMISSION REGULATION (EU) 2019/424
[26] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0424
[27] https://www.thegreengrid.org/resources/library-and-tools/wp-94-itwc-methodology-calculate-server-work-capacity-cserv-data

calculations at different precision levels, the precision at which the maximum TPP number is reached is always used.

The C_{Stor} metric describes the total storage capacity and therefore is a good additional performance metric for data centres. Important context is given by the additional information on the WUE category, the PUE category, the local cooling degree days and the availability / redundancy level.

The right-hand element for describing other sustainability actions and circularity measures

Figure 11 - The right-hand segment of the data centre sustainability label



The element on the right-hand side is also divided into an upper part, which describes waste heat utilisation, and a lower (voluntary) part, which shows further sustainability measures.

In the case of waste heat utilisation, a distinction is made between A) the basic willingness to provide waste heat and whether a data centre officially (bindingly) offers this and B) the waste heat used (partly outside the influence of a data centre operator).

This section includes voluntary information on further sustainability measures to reflect themany options and measures that can improve the sustainability of data centres. This dedicated space is proposed in order to show the broad impact (beyond energy and water consumption) a data centre can have on sustainability and to demonstrate what ambitious data centre operators put in place.. However, the use of these sustainability points need to be clearly defined and linked to minimum thresholds:

	Other heat reuse actions (excluded in ERF)	**Definition**: Internal Reused Energy: Energy recovered and reused within the facility (e.g. preheating diesel engines, reheating ventilation air), which is not reflected in the ERF. **Requirement**: At least one internal application which reuses the heat, which is not reflected by the ERF.
	Grid functions	**Definition*:*** The data centre participates in programmes that support the electrical grid by adjusting power consumption or generation in response to signals from the grid operator (e.g. demand response, ancillary services).

		Requirements: *≥10% of annual energy use* is available for load shifting or shedding (via automation or active participation in grid programmes) OR the data centre participates in at least two types of ancillary/grid services (e.g., frequency regulation and spinning reserves).
	Hardware circularity/ e-waste program	**Definition**: An established programme to refurbish, reuse, or recycle hardware components to minimize e-waste and maximize material reuse. **Requirements**: *≥75% of decommissioned IT equipment* is either reused, refurbished, or recycled through certified partners (e.g. *Responsible Recycling ("R2") Standard*[28], e-Stewards[29]) AND an audit trail is maintained for all hardware retirement.
	Low GWP refrigerant	**Definition:** Use of refrigerants with a Global Warming Potential (GWP) below conventional thresholds, contributing to lower climate impact in cooling systems (or no refrigerant is used). **Requirements**: All cooling systems use refrigerants with *GWP < 150*, aligning with the EU F-Gas Regulation[30] best-in-class.
	Liquid cooling >75%	**Definition**: Deployment of direct-to-chip, immersion, or rear-door heat exchanger-based cooling solutions in place of or in addition to traditional air cooling. **Requirements**: *≥75 % of IT load* is cooled using liquid cooling systems.
	Brownfield approach (>80% of area used before)	**Definition:** Data centre is built on a previously developed site (e.g. industrial/commercial land), avoiding ecological degradation or greenfield construction. **Requirement:** *≥80% of site area* was already developed prior to construction.
	Water stewardship programme	**Definition**: A holistic approach to minimizing water consumption, managing local watershed impacts, and transparent water reporting. **Requirement**: Participation in a recognized stewardship initiative (e.g. Alliance for Water Stewardship certification[31], watershed restoration programmes).
	High share of hourly matched green power	**Definition:** Purchase of high-quality power that assures, that green power is produced (generation/storage) at the same hour it is consumed. **Requirement:** *More than 80% of the electricity consumed* is verifiably generated at the same hour as it is consumed in the data centre.

iv. Implementation of the rating scheme

With the Commission Delegated Regulation (EU) 2024/1364 of 14 March 2024, the first phase of the establishment of a common Union rating scheme for data centres has already formally started. With the reporting requirements, data has been collected on energy use, energy efficiency, reused heat and further sustainability metrics of data centres. This regulation already aims to establish a rating scheme for the sustainability of data centres and therefore already provides a legal basis.

In addition to the label, which reflects the sustainability of individual data centre locations, the authors propose to set up a dashboard that calculates and clearly displays high-level trends in sustainability in data centres in the member states as well as EU overall trends. Such a dashboard would require good plausibility checks and filtering functions to produce meaningful results. Especially in the first

[28] https://sustainableelectronics.org/r2/
[29] https://e-stewards.org/
[30] https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/f-gas-legislation_en
[31] https://a4ws.org/aws-standard/aws-standard-certification/

few iterations, when results are generated automatically, they should be critically reviewed by humans.

Publication of data centre sustainability labels

A very crucial, but highly debated topic is the public transparency of a label with data centre KPIs. Such a label can only have its full effect and help market players choose the data centre that best suits their sustainability priorities through disclosure. For example, water consumption may be a critical factor for customers in southern countries, while waste heat utilisation may be more important in northern countries. Allowing local customers to make their own choices in support of market-based competition for sustainability is probably a good complement to the high degree of freedom that minimum performance standards (see chapter 3.b) allow.

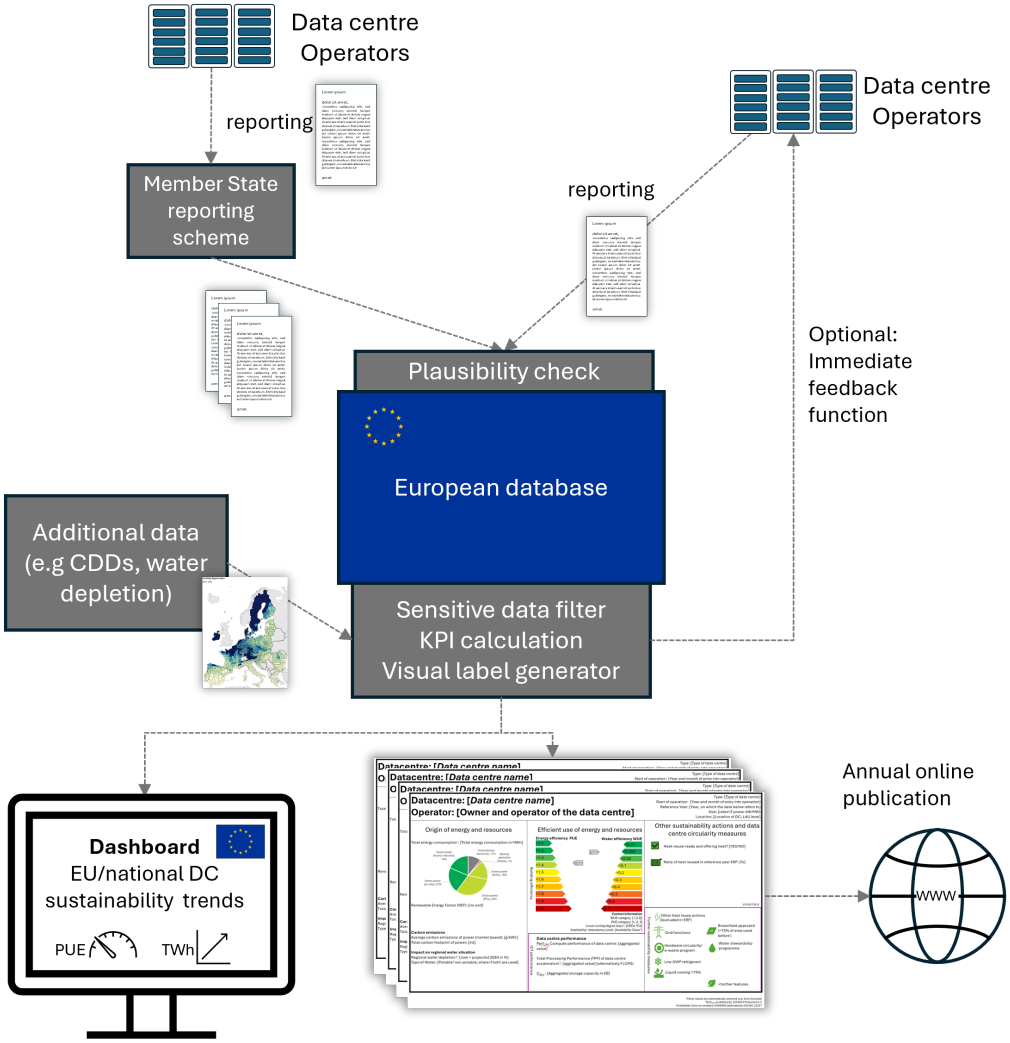
Most data centre operators, especially large cloud companies, consider their data as business sensitive. Especially on capacity utilisation (which can to a certain degree be derived from electricity consumption) some operators are afraid this could weaken their competitive position. At the same time, the reporting and transparency of energy consumption and the origin of these energy quantities are fundamentally important for a meaningful assessment of sustainability.

The total energy consumption seems to be the most sensitive metric according to the letters of the stakeholders. The same applies for the total carbon emissions which can, in combination with the carbon intensity of power be used to calculate backwards the total energy consumption. These metrics are on the other side a very relevant transparency information and thus are recommended to be kept on the label. However, whether the operators' trade secrets outweigh the public interest in transparency is less a technical question than a political one, which cannot be conclusively answered here.

If the label is to be published, it should be also published in a machine-readable format and, if necessary, via central institutions (EU database of data centres) and on the operator's website (voluntarily). Such formats can also help customers to automatically assign their workloads to the best data centre in terms of sustainability. The label itself can also be played back directly to the operator when entering their data, even before publication. This has the advantage that the data is checked during entering, and any major errors should be noticed immediately.

Figure 12 illustrates how the label could be integrated based on the existing reporting according to the EED. Additionally, it shows a dashboard for EU / Member States wide trends. Such a dashboard is currently in discussion with the implementing partner of the EU database.

Figure 12 - The proposed integration of the label into the already established reporting



To roll out the labels, at least another round of data collection (2024) should be completed including plausibility checks to have a good starting point that reflects as much as possible the status quo in the industry. Operators of small data centres below the 500-kW threshold should be actively motivated to voluntarily report their data, receive a label and still have the choice if this will be published.

b. Task 2.2 – Assess the need and identify and propose ways to improve the energy efficiency of data centres, including establishing minimum performance standards

This chapter assesses the need for improving the energy efficiency of data centres and explores options for establishing MPS. In order to identify relevant benchmarks for setting realistic and impactful MPS, a comprehensive review of existing regulatory frameworks voluntary initiatives and best practice guidelines was conducted. The analysis focused on key sustainability indicators such as PUE, WUE, REF and ERF. The chapter begins with a review of external standards policies and voluntary initiatives followed by a summary of stakeholder feedback from surveys workshops and interviews. The analysis of reported data on core KPIs provides the empirical foundation for formulating realistic MPS. Proposed thresholds are outlined and linked to governance and verification requirements. Finally, the chapter integrates Best Available Techniques (BATs) including their feasibility and potential impact to support the achievement of the proposed standards.

i. Review of external standards, policies and initiatives

Here a summary of the reviewed external standards, policies and initiatives is presented:

- **Green Public Procurement Guideline**[32]

This initiative outlines progressive targets across several indicators, including PUE, WUE, REF, ERF, CER and CUE. A phased reduction is defined, with PUE decreasing from 1.5 (2025) to 1.2 (2031) for existing data centres, alongside comparable design requirements for new facilities. The WUE target is set at 0.2 m³/MWh by 2040. REF is expected to reach 80 % and ERF 60 % by 2031. Targets for CUE (5.7 kg/kWh) and CPU utilization are also included, forming a time-bound and multi-dimensional framework.

- **Guide to Environmental Sustainability Metrics**[33]

This guideline provides indicative benchmarks rather than mandatory thresholds. A PUE range of 1.2–1.3 is indicated, assuming 75–85 % load. Additional references include WUE (0.30–0.45 m³/MWh), ERF (0.75–1), and CUE (0–0.12 kg/kWh). These values are presented as best-practice references, based on operation under favourable conditions.

- **Climate Neutral Data Centre Pact (CNDCP)**[33]

The CNDCP includes voluntary targets, with a PUE of 1.3–1.4 for both existing and new data centres, depending on the respective climate zone. A WUE of ≤ 0.4 m³/MWh is defined as the reference baseline for potable/fresh water in cold climates with high water stress and is adjusted according to climate, water-stress and water-type factors[34]. REF is targeted to reach 100 % by 2030, with 75 % as an interim level. No ERF threshold is defined, though participants are encouraged to assess heat reuse potential. The framework allows for self-defined targets and regional flexibility.

- **Directive GB 40879-2021 (China)** [33]

This regulation sets mandatory PUE limits, which vary between 1.15 and 1.5 depending on system size and load. It reflects a binding energy efficiency framework but does not address additional indicators such as WUE or REF.

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[32] United Nations Environment Programme (UNEP), United for Efficiency (U4E). (2024, February). *Green Public Procurement Technical Guidelines and Specifications on Data Centres and Servers*.

[33] Schneider Electric, Energy Management Research Centre – White Paper 67, Version 2 (June 2023), authored by Paul Lin, Robert Bunger, and Victor Avelar

[34] https://www.climateneutraldatacentre.net/wp-content/uploads/2025/09/White-paper-on-DC-responsible-use-of-water-review-2024.pdf

- **Project DC-CFA (Singapore)** [33]

Singapore's initiative recommends a PUE target of 1.3 under 100 % load conditions. Similar to the Chinese directive, it focuses exclusively on energy efficiency (PUE), with no accompanying guidance on water, renewables, or reuse.

- **German Energy Efficiency Act (BGBl. 2023 I Nr. 309) (Germany)** [35]

The German Energy Efficiency Act defines binding performance targets. For data centres commissioned before July 2026, a PUE ≤ 1.5 is required from July 2027 and ≤ 1.3 from July 2030. New facilities (post-July 2026) must reach PUE ≤ 1.2 within two years of operation. Mandatory ERF thresholds apply to new facilities: 10 % (from mid-2026), 15 % (from mid-2027), and 20 % (from mid-2028). Renewable energy coverage must reach 50 % by 2024 and 100 % by 2027. These requirements are aligned with the EU reporting obligations.

- **Noord-Holland Initiative**[36]

This regional framework proposes a design PUE of 1.16 for large data centres (> 5 MW). No further sustainability indicators or implementation timelines are specified.

- **Blauer Engel (Blue Angel) label**[37]

Germany's ecolabel defines stringent PUE benchmarks (down to 1.25), mandates 100 % renewable energy, and requires some form of waste heat reuse (> 0). It also recommends a minimum CPU utilisation of 20 %. While not mandatory, this label represents a high-performance standard for environmentally conscious data centres.

A table summarizing the values proposed by these initiatves can be found in the Annex 4 – External Standards, Policies and Initatives.

ii. Feedback from stakeholders regarding MPS

To inform the development of realistic and effective MPS, extensive feedback was gathered from stakeholders through surveys, workshops, interviews and follow up consultations

Stakeholder Survey

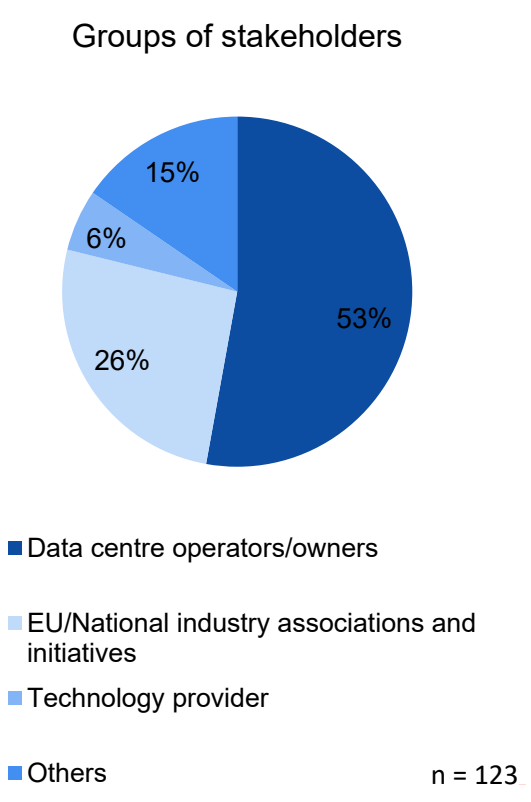
The stakeholder survey was launched on February 21st, 2025 and closed on March 31st, 2025. 148 responses were collected, out of which, 123 were eligible for further analysis (see Figure 13). Detailed information on the structure and questions of the survey can be found in Annex 1 – Surveys/Interviews.

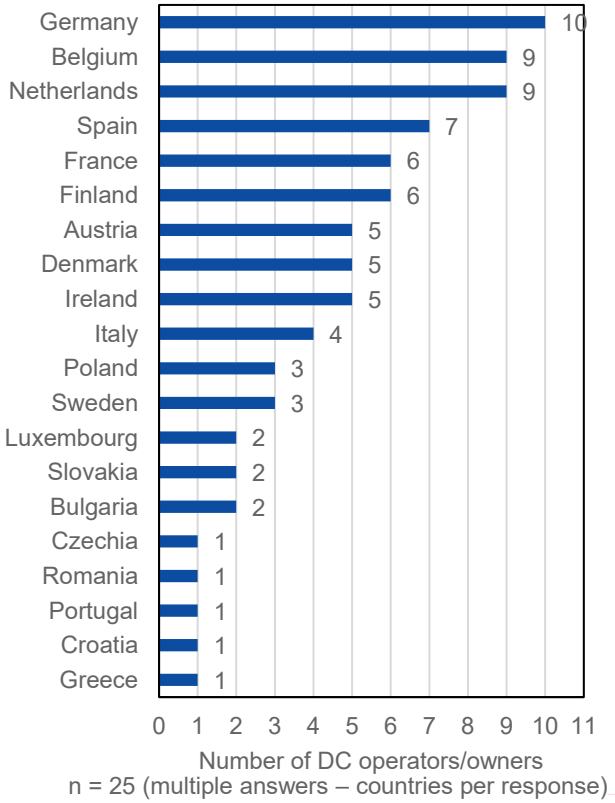
Figure 13 - Survey Participation

[35] Bitkom e. V. (2024). *Energieeffizienzgesetz für Rechenzentren – Vorgaben und Umsetzung (Version 1.1)*. https://www.bitkom.org/sites/main/files/2024-01/bitkom-leitfaden-energieeffizienzgesetz-fuer-rechenzentren.pdf

[36] Buck, M. (n.d.). *Why Data Centres Should Feature Prominently in the Clean Industrial Deal*.

[37] Gröger, J., & Behrens, F. (n.d.). *Umweltzeichen Blauer Engel für Rechenzentren*.





The results indicate a high degree of maturity in sustainability planning across the sector: 91% of respondents reported having an internal sustainability plan in place, with 83% expecting to meet their goals within the next five years. Key drivers for developing these plans included customer demand (29%), economic considerations (26%), regulatory pressure (23%), and internal commitment (23%).

Declared goals most frequently addressed carbon-free energy (44.4%), followed by PUE reduction (25.9%), WUE reduction (22.2%) and zero waste (7.4%). When asked whether MPS should be mandated, responses were mixed: 47% of respondents were in favour (answering “yes” and “probably yes”), while 53% were opposed or sceptical (answering “no” or “probably no”).

Supporters of MPS cited higher sustainability ambitions (56%) and incentives for smaller data centres to improve efficiency as main support drivers. Among opponents of MPS, concerns included the heterogeneity of data centre types and climate conditions (50%), existing mandates (28%), and doubts about effectiveness of MPS (17%). Regarding differentiation, 30% recommended setting thresholds as a function of contextual factors such as climate, age or size, while others highlighted the need to distinguish between data centre business models or to consider indicator interdependencies.

This feedback demonstrates a strong internal drive for improvement among many stakeholders, alongside a call for flexibility and proportionality in the design of regulatory interventions.

The interview guideline is provided in Annex 1.

Feedback from Workshop 3

During Workshop 3, stakeholders discussed the completeness and quality of the first reporting period, shared their experience with the reporting process and engaged in an initial debate on MPS. The main points raised were:

- **Data completeness and quality**: Only about 40% of EU data centres submitted data, with significant gaps in coverage across Member States. Around 23% of entries were flagged as potentially unreliable due to implausible PUE values, energy densities or inconsistent floor area figures. Participants stressed the need for stronger validation and harmonisation of definitions.
- **User experience**: Many stakeholders found the reporting platform difficult to use, with 40% citing navigation issues and almost 90% reporting technical problems. Instructions and definitions were often unclear. Suggested improvements included API integration, Excel/JSON data import, removal of redundant or customer-related metrics, harmonisation across Member States, and safeguards for sensitive business information.
- **MPS:** Stakeholders were divided. Poll results showed 42% considered the proposed MPS balanced, 37% saw them as too strict and 22% as not strict enough. Concerns focused on climate and technology diversity, potential unfairness for operators in hotter regions, and risks of market distortion. Supporters underlined the importance of ambitious sustainability goals and a level playing field.
- **Specific benchmarks:** Participants noted that newer and co-hosting data centres tend to achieve better PUE values than older or enterprise models, and that climate conditions play a major role. Some data on cooling degree days appeared implausible, highlighting the need for standardised climate adjustment.
- **Future design of standards**: Stakeholders recommended reconsidering MPS every 3 to 5 years, accounting for technological developments. Many warned against one-size-fits-all targets for PUE and WUE and argued for climate-based differentiation, similar to the approach of the Climate Neutral Data Centre Pact.

Overall, the feedback reflected both recognition of the need for binding standards and caution about their design, with calls for proportionality, differentiation by context and careful alignment with existing reporting obligations.

Feedback from Workshop 4

During Workshop 4, stakeholders continued the debate on the introduction of MPS. Discussions focused on feasibility, fairness and regional adaptation, with the following main points raised:

- **Feasibility of uniform targets:** Many participants questioned the application of the same PUE and WUE thresholds across different climates, technologies and data centre sizes. Smaller and older facilities were identified as the most challenged in achieving PUE < 1.5 by 2030, leading to calls for differentiated targets or simplified reporting obligations.
- **Water usage requirements:** The majority supported linking WUE obligations to local scarcity conditions, while others preferred uniform EU wide thresholds for consistency and comparability. Strong emphasis was placed on the need to integrate cooling technologies into reporting to better capture differences in water and energy use.
- **Renewable energy targets:** Stakeholders largely supported the proposed goal of 100% renewable energy consumption by 2030. At the same time, many underlined the importance of incentivising more advanced approaches such as hourly matching rather than relying solely on GoOs and PPAs.
- **Transparency and implementation:** Participants highlighted that successful MPS require clarity in definitions, strong data quality controls and proportional implementation to avoid excessive administrative burden. Suggestions included improved alignment with national regulations and practical incentives for innovation and efficiency improvements.

Overall, feedback from Workshop 4 recognised the necessity of MPS as a policy tool but stressed that their design must remain flexible, realistic and sensitive to the diversity of data centres across Europe.

Conducted Interviews

During the course of this project interviews were conducted with key stakeholders among which were, Uptime Institute, Nvidia, Microsoft, Google, AWS, Digital Realty, Danfoss, EUDCS, Digital Europe and others.

Stakeholders expressed caution and critical view regarding the introduction of MPS for individual KPIs. Among the risks and concerns with MPS mentioned are:

- **Innovation Barriers**: MPS could hinder the adoption of innovative technologies that offer long-term sustainability benefits, but don't immediately meet traditional benchmarks.
- **Lack of Flexibility**: MPS fail to reflect the significant variations in climate, resource availability, infrastructure, and cooling technologies across EU Member States.
- **Premature Regulation**: Many argue the market is already driving sustainability progress (especially in AI and accelerated computing), and that premature or rigid standards may backfire, pushing data centres to relocate outside the EU.
- **Insufficient Data**: The industry lacks comprehensive and consistent data to define meaningful, fair, and enforceable minimum standards at this stage.

Suggestions for the introduction of MPS are among others:

- **New vs. Existing data centres**: If MPS are to be introduced, they should apply only to newly built facilities. Existing ones need flexibility, tailored targets, and enough time (2–3 years) to adapt.
- **Technological Readiness**: Measures must account for what is technologically and economically feasible today, including limitations of older infrastructure.
- **Context-Sensitive Standards**: Any performance target must consider location-specific factors such as ambient temperature, water availability and power grid constraints.
- **Using Benchmarks from Existing Voluntary Industry Commitments**: Many operators already follow self-imposed performance targets under initiatives like the CNDCP.
- **Third-Party Verification**: If standards are adopted, a robust independent audit and certification system must be included to ensure fair implementation and data accuracy.
- **Incentives over Mandates**: Stakeholders prefer market-based incentives or regulatory frameworks (for example voluntary initiatives such as the CNDCP launched in 2021)instead of rigid mandates.

While there is support for improving sustainability and encouraging best practices, stakeholders do not uniformly support binding MPS across the board. Instead, they recommend a phased, flexible, and evidence-based approach that reflects the complexity of the sector and avoids undermining innovation, investment, and Europe's competitiveness in the global data economy.

Additional Feedback from Stakeholders after Workshop 4

Following the fourth workshop, stakeholders provided further feedback on the introduction of MPS:

- The importance of sustainability and the need to eliminate persistently inefficient facilities was widely recognised.

- Most participants stressed that binding standards are premature, as only the first EED reporting cycle is completed and at least two full cycles are needed before reliable benchmarks can be set.
- Concerns were raised about fairness and feasibility, since metrics such as PUE and WUE are strongly influenced by climate conditions, water availability and cooling technologies.
- Without proper climate normalisation, operators in warmer or water-stressed regions risk being penalised despite comparable efficiency efforts.
- Smaller and older facilities were highlighted as particularly vulnerable, as they may lack the resources to meet uniform thresholds.
- Rigid MPS could discourage innovation, create market distortions and reduce regional diversity of investment.
- Stakeholders emphasised that MPS should not be misused as a tool to drive ambition or innovation, which should remain the role of rating schemes, voluntary initiatives and incentive-based instruments.
- Some organisations supported the principle of MPS, provided that they are phased in gradually, aligned with the rating scheme and designed to evolve over time.
- Several recommended limiting the application to new facilities initially, while allowing existing ones flexibility and sufficient adaptation time.
- Additional suggestions included third-party verification, improved data quality controls, stronger incentives for renewable energy procurement, and better alignment with national regulations.
- Overall, stakeholders agreed that MPS could be useful in the long term if they are based on robust data, clear objectives, climate-adjusted benchmarks, and harmonised EU implementation to ensure both effectiveness and fairness across diverse operating contexts.

iii. Analysis of reported data

To ensure consistency and comparability, the proposed MPS were derived directly from the data submitted through the existing reporting system. This approach was selected primarily due to the lack of alternative data sources and to minimise the reporting burden on the data centres. In total, there are 748 reported entries, of which about 600 reported entries were available for further evaluation, with a focus on the core KPIs: PUE, WUE, ERF and REF.[38] Depending on the KPI, not all entries could be used. For example, PUE could only be calculated for 600 data points, and WUE for 405, due to missing values such as IT energy demand. As reporting practices develop, additional indicators may be included and the MPS refined accordingly.

Power Usage Effectiveness (PUE)

The PUE was calculated based on the reported total annual energy consumption in kWh divided by the total energy consumption of the IT equipment in kWh. Climate conditions (represented by CDD), size (represented by the installed IT power demand in kW), age of the data centre and data centre type were identified as the main factors impacting the PUE.

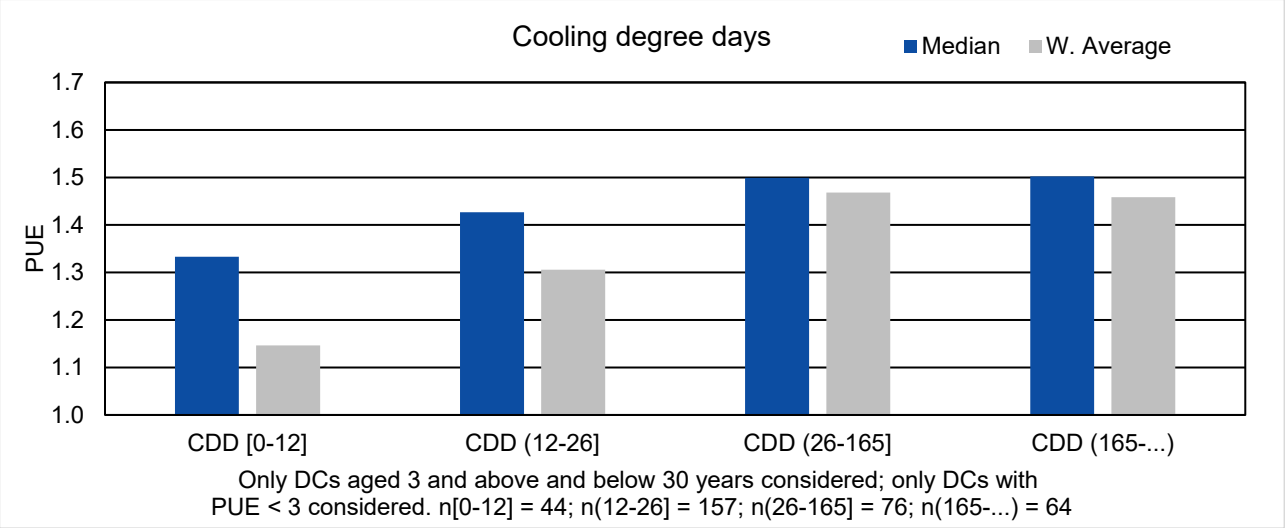
[38] calculated according to the methodologies defined in Commission Delegated Regulation (EU) 2024/1364, Annex III

The reported CDD values were grouped for analysis according to the values published by Eurostat[39,40]. As Eurostat publishes continuous CDD values, the class boundaries used here follow the official Eurostat map legend for consistency.

- CDD in the range of [0-12] with 44 data centres,
- CDD in the range of [12-26] with 157 data centres,
- CDD in the range of [26-165] with 76 data centres, and
- CDD in the range of [>165] with 64 data centres.

Figure 14 below outlines the median and the weighted average of PUE for the different climate zones, using total annual energy consumption as the weighting factor[41].. Generally, an increasing value of PUE in relation to the CDD can be observed, which can be related to higher cooling demands. The median is generally above the weighted average,which signals that larger data centres in terms of total energy consumption are generally more efficient. Both values do not go beyond PUE 1.5, highlighting that, for the majority of data centres, this value can already be achieved today, even in hot-climate zones. This allows the conclusion that a PUE of 1.5 could be uniformly used across different climate zones within the EU.

Figure 14 - PUE in relation to Cooling Degree Days



To account for the age of different data centres, four age groups were defined. Based on the reported data:

- 84 data centres were reported to be 0–3 years old,
- 65 were reported to be 4–6 years old,
- 62 were reported to be 7–10 years old, and
- 245 were reported to be older than 10 years.

[39]https://ec.europa.eu/eurostat/statistics-explained/SEPDF/cache/92378.pdf

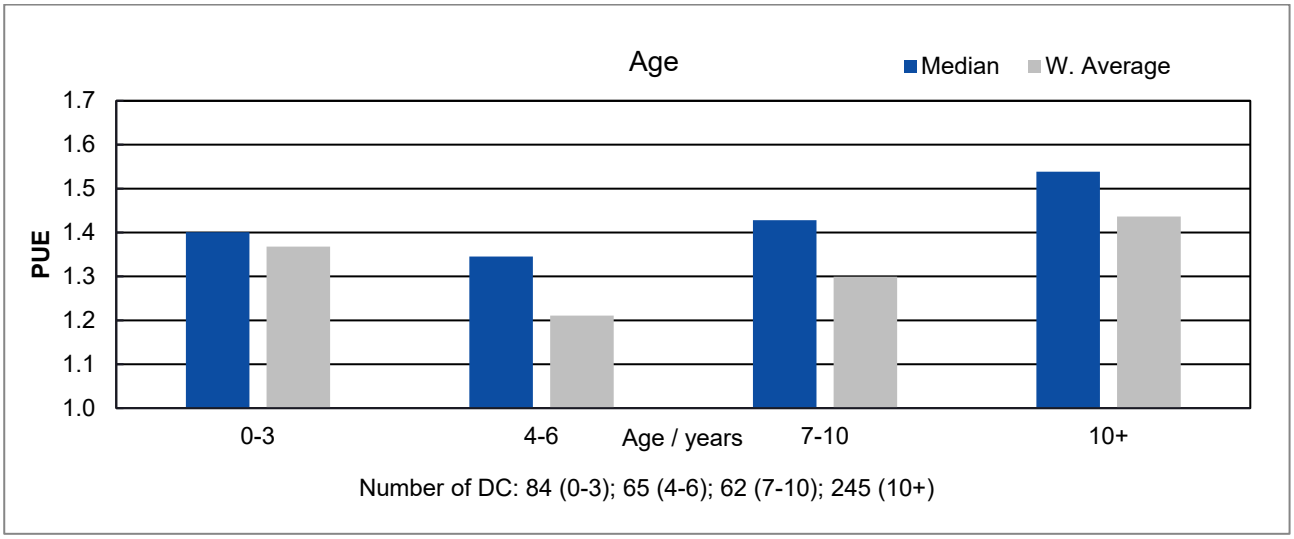
[40] Eurostat calculates CDD as continuous values. The class boundaries (0–12, 12–26, 26–165, >165) are not part of the methodology but were chosen for cartographic clarity in the official Eurostat visualisation. We adopt the same classes here for consistency.

[41] Annex IV of Commission Delegated Regulation (EU) 2024/1364

The PUE of the 0–3 years group is higher than that of the 4–6 years group, but it increases again with age. This can be attributed to a ramp-up period, where there is a high discrepancy between operational and design PUE. After three years, data centres tend to approach their design PUE.

The median and the weighted average of data centres commissioned within the past 10 years generally achieve a PUE below 1.5. The weighted average of all age groups lies below the median, suggesting that larger facilities tend to operate more efficiently. Only data centres older than 10 years exhibit PUE values above 1.5. Given the pace of technological development and the growing demand for new infrastructure, there is a clear need to retrofit older data centres to improve energy performance.

Figure 15 - PUE in relation to Age



A total of 451 data centres specified their type. For analytical clarity, three main categories were defined:

- enterprise data centres (160 sites),
- co-location data centres (244 sites), and
- co-hosting data centres (45 sites).

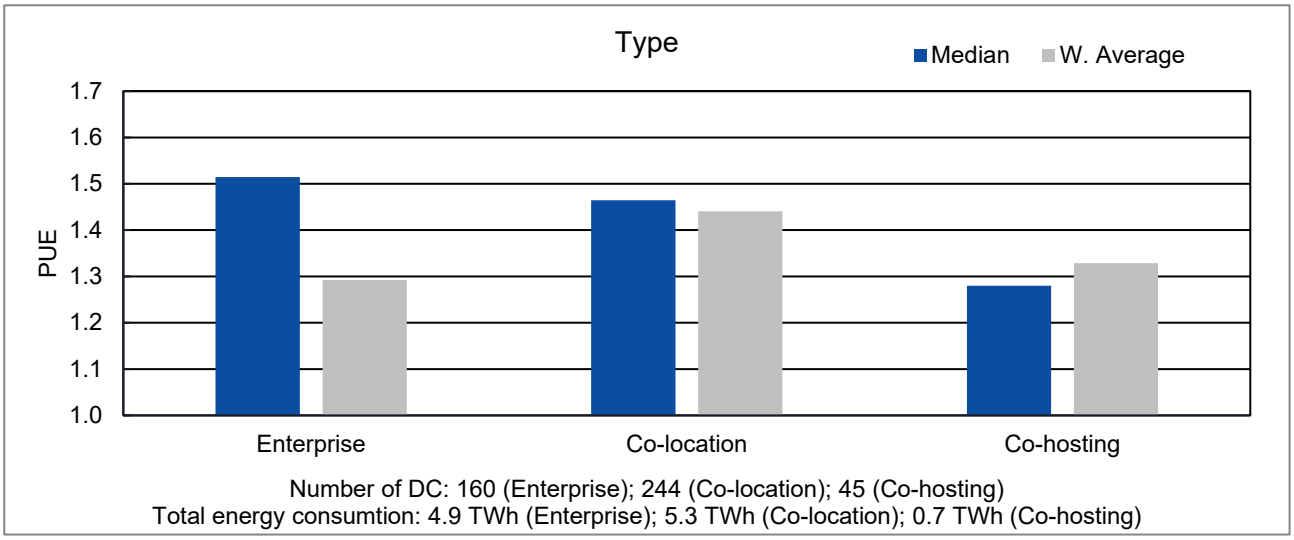
While several sub-types exist, such as single or grouped structures and hybrid forms combining co-location and co-hosting, these were not further differentiated due to the limited sample sizes per category.

In terms of total energy consumption:

- Co-hosting data centres accounted for the lowest share, with 0.7 TWh.
- Enterprise data centres consumed 4.9 TWh.
- Co-location data centres led with a consumption of 5.3 TWh.

All three types remained below a PUE of 1.5 in both median and weighted average terms, an exception of which is the median of enterprise data centres, which lies slightly above 1.5. This suggests that, across types, larger data centres (which dominate the energy mix) tend to be more energy efficient. The slightly higher weighted average for co-location data centres also reflects their larger share in the total energy consumption. Co-hosting data centres showed a higher weighted average compared to the median, which indicates that the the sites with the highest energy consumptionin this category tend to be less efficient.

Figure 16 - PUE in relation to Data Centre Types



To assess the energy efficiency across data centre sizes, five categories were defined based on the installed IT power[42]. Only data centres older than three years and with a reported PUE below 3 were considered to exclude distorted values caused by ramp-up effects or outliers. In total:

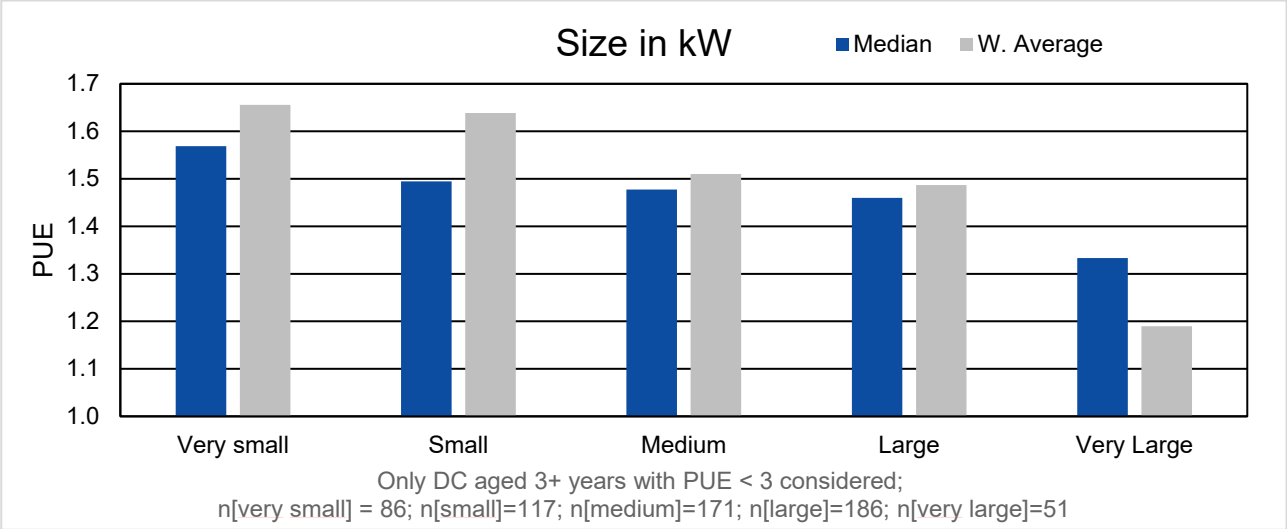
- 86 data centres were classified as very small (100–500 kW),
- 117 data centres were classified as small (500–1 000 kW),
- 171 data centres were classified as medium (1–2 MW),
- 186 data centres were classified as large (2–10 MW), and
- 51 data centres were classified as very large (>10 MW).

Notably, very small data centres fall below the 500-kW reporting threshold set by the EED and are, therefore, not formally required to report.

While the median is higher than the weighted average for very large data centres, signalling that the energy-intensive very large data centres tend to be more efficient, this changes the smaller the data centres get. A trend can be observed, that the larger the data centres become, the lower the PUE they achieve, highlighting economies of scale. This reflects known structural advantages such as scale, better infrastructure, and higher utilisation in large facilities.

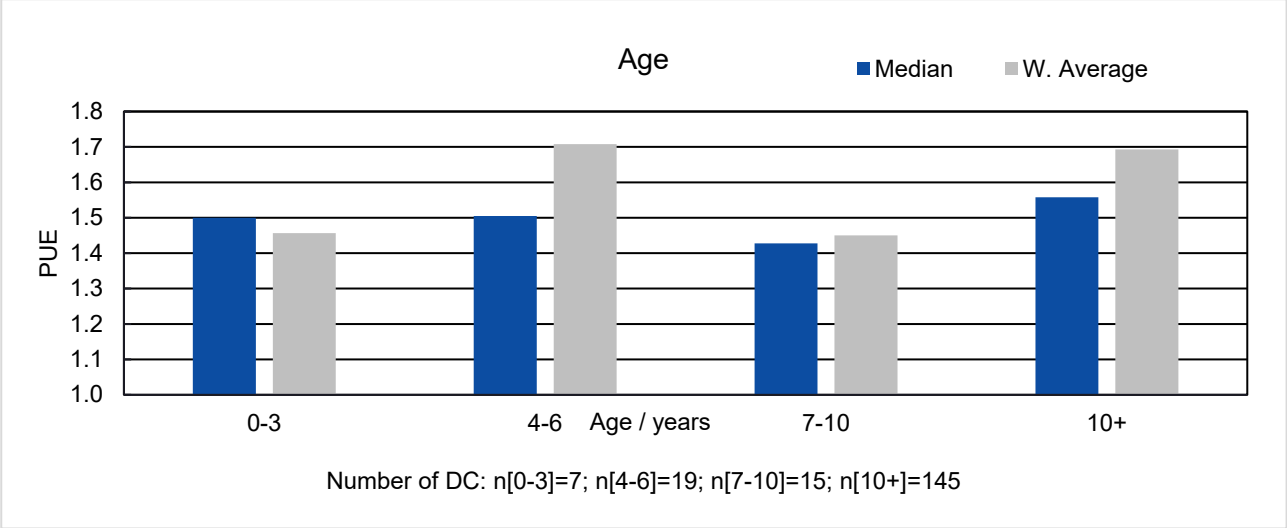
[42] DELEGATED REGULATION (EU) 2024/1364

Figure 17 - PUE in relation to Size in kW



To better understand why very small and small data centres tend to show higher PUE values, their performance was analysed in relation to age (see Figure 18). While it is technically possible for newer data centres in these size categories to achieve a PUE below 1.5, their share within the sample is limited. Only 14% of all reported data centres were very small and 19% were small, and these groups together accounted for just 7% of the total reported energy consumption. In contrast, 78% of all reported very small and small data centres were older than 10 years and this group also showed the highest PUE values. This suggests that many small-scale facilities operate on outdated infrastructure. Targeted retrofitting of ageing very small and small data centres would therefore be a necessary step to improve energy efficiency in this segment.

Figure 18 - PUE for very small - small data centres in relation to age



Summary on PUE:

In summary, the analysis confirms that PUE is influenced by several structural and operational factors. Warmer climate zones, indicated by higher CDD, are generally associated with higher PUE values due to increased cooling demand. Nonetheless, values below 1.5 are still achievable in most cases even under challenging climatic conditions. Data centre size plays a decisive role, with larger facilities consistently showing lower weighted average PUE, reflecting economies of scale, higher utilisation and more efficient infrastructure. Age is another key factor, as older data centres tend to

show higher PUE values, especially in the very small and small categories, which often rely on outdated systems. To capture this segment more accurately, very small data centres (100–500 kW) could be included in the reporting (possibly under a lighter regime). The data also shows that, across different data centre types, energy efficiency is broadly comparable, although co-location centres, which dominate total energy consumption, slightly raise the overall average. Overall, the results underline the importance of targeted retrofitting efforts, particularly for smaller and older data centres, as well as the relevance of climate-sensitive design strategies to maintain high energy efficiency across Europe.

Water Usage Effectiveness (WUE)

Figure 19 shows the WUE based on the reporting category used for Total Water Input, as defined in EN 50600-4-9. WUE was calculated as total water input (m^3) divided by the energy consumption of the IT equipment (kWh), further expressed in m^3/MWh. Two reporting categories exist and are currently allowed within the reporting scheme: Category 1 includes all physical water input, while Category 2 accounts for the net water input by subtracting water output reused for non-industrial purposes.

For this analysis only data centres that reported water usage were considered. As cooling methods are not reported it was not possible to verify whether a water usage of 0 is valid or not. Among the data centres with complete data for both median and weighted average calculation of the WUE, 19 reported according to Category 1 and 235 according to Category 2. While the median WUE for both categories is comparable, the weighted average is significantly higher for Category 2. This suggests that large-scale data centres reporting under Category 2 have substantially higher absolute water use. However, due to the large difference in sample sizes between the two categories, a direct comparison of the results is not meaningful. For the further evaluation of the WUE, only Category 2 and only data centres older than 3 years, considering the ramp-up period were taken into account.

Figure 19 - WUE in relation to reporting category

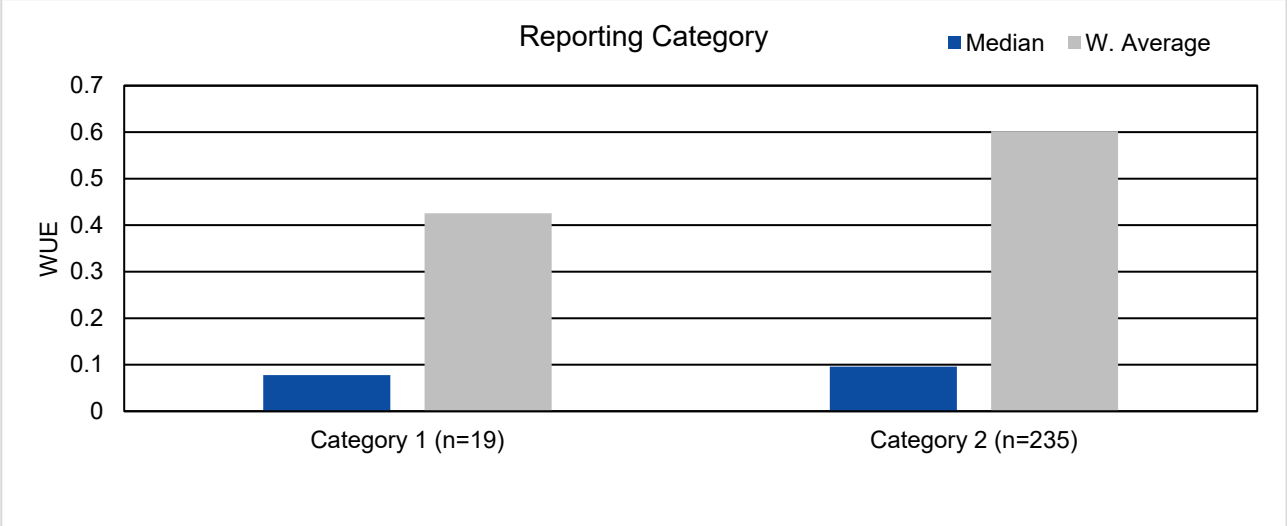


Figure 20 shows the median and weighted average of WUE across different climate zones, using the reported CDD value. The group with CDD [12–26] represents the largest sample with 187 data centres. Across all zones, the median WUE remains below 0.2, indicating that at least half of the data centres in each group operates with relatively low water usage. In contrast, the weighted average is significantly higher in most cases, especially in the lower CDD ranges (0–12 and 12–26). This suggests that a small number of high-consuming data centres, likely larger facilities, disproportionately increases the average. One possible explanation is the use of evaporative or adiabatic cooling systems in these sites. However, a more detailed interpretation is limited by the lack of data on specific cooling technologies in the reporting.

Figure 20 - WUE in relation to Cooling Degree Days

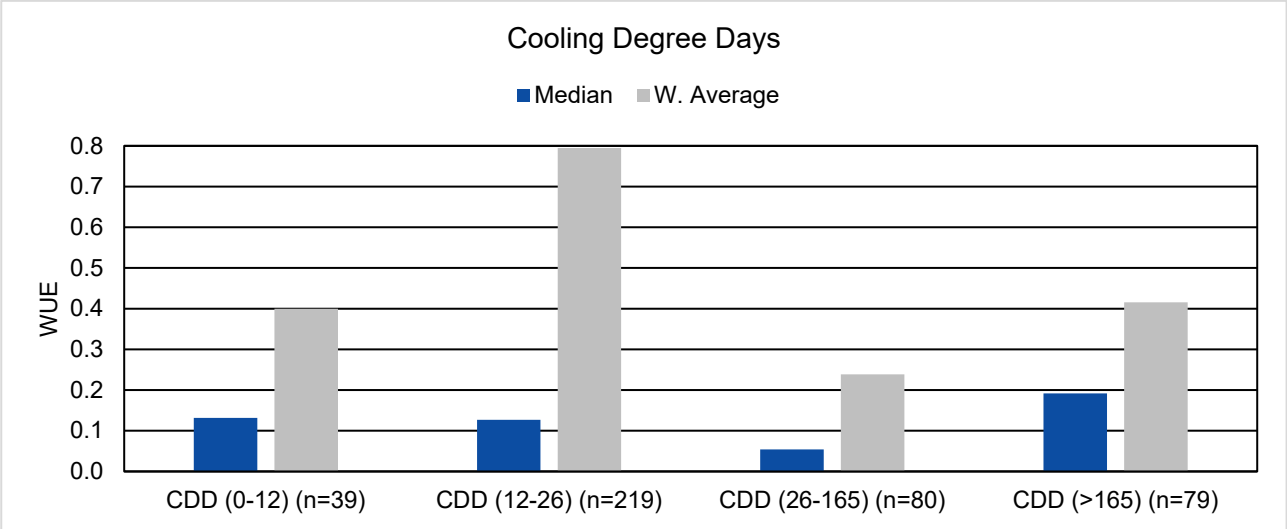


Figure 21 illustrates the WUE in relation to data centre age. The largest group consists of data centres older than ten years. Across all age groups the median WUE remains below 0.2 m³/MWh, indicating generally low water consumption for at least half of the facilities in each group. However, the weighted average is considerably higher, particularly for data centres aged 4 to 6 years. This suggests that facilities in this age group may be larger and make use of efficient cooling technologies in terms of PUE but also require significantly more water. When compared with climate distribution in Figure 20, it appears that many of these data centres are located in moderate climate zones where water stress tends to be lower[43]. As the trend moves toward larger high-performance data centres with increased water demand, retrofitting strategies for older data centres should aim to improve both energy and water efficiency.

Figure 21 - WUE in relation to Age

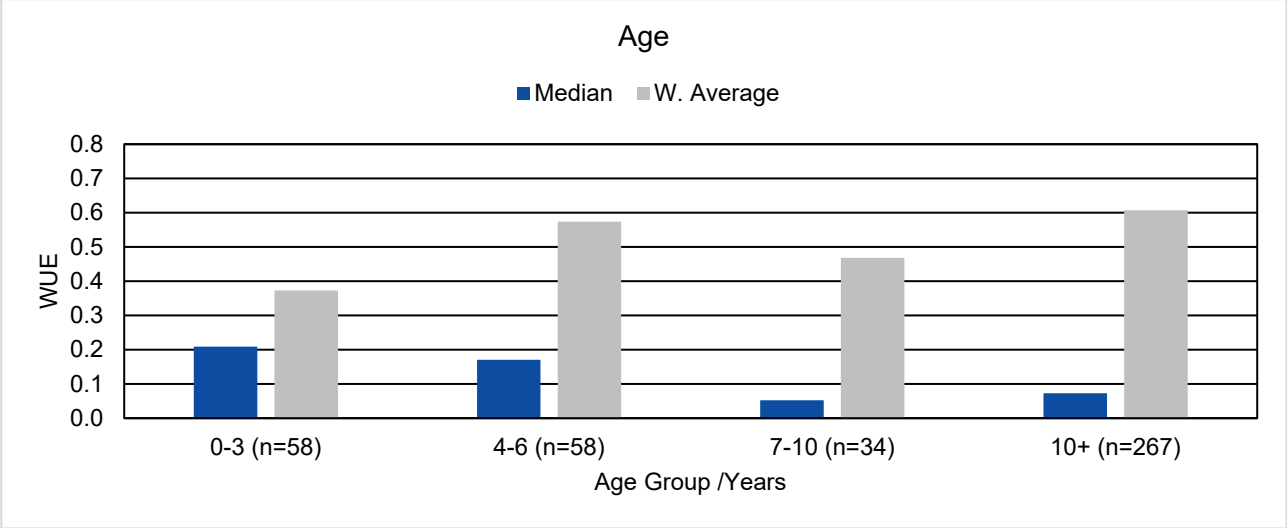


Figure 22 illustrates the WUE for the three main reported data centre types. Co-location represents the largest group with 126 entries, followed by enterprise and co-hosting data centres. All three categories achieve a median WUE below 0.3 m³/MWh, indicating that at least half of the facilities in each group operate with relatively low water intensity. However, the weighted average is significantly higher, especially for enterprise and co-location data centres, suggesting that large-scale sites with

[43]https://www.wri.org/applications/aqueduct/water-risk-atlas

high energy and water consumption dominate the overall picture. The particularly high weighted average and median in the enterprise suggests that this category as a whole tends to be more water-intensive. In contrast, co-location sites show a wider range but with fewer extreme outliers, suggesting more standardised infrastructure and potentially broader adoption of water-efficient cooling technologies. Co-hosting data centres show the lowest values overall, which is consistent with their typically smaller scale and limited resource demand. These differences highlight how operational models and ownership structures may influence water performance in practice.

Figure 22 - WUE in relation to Type

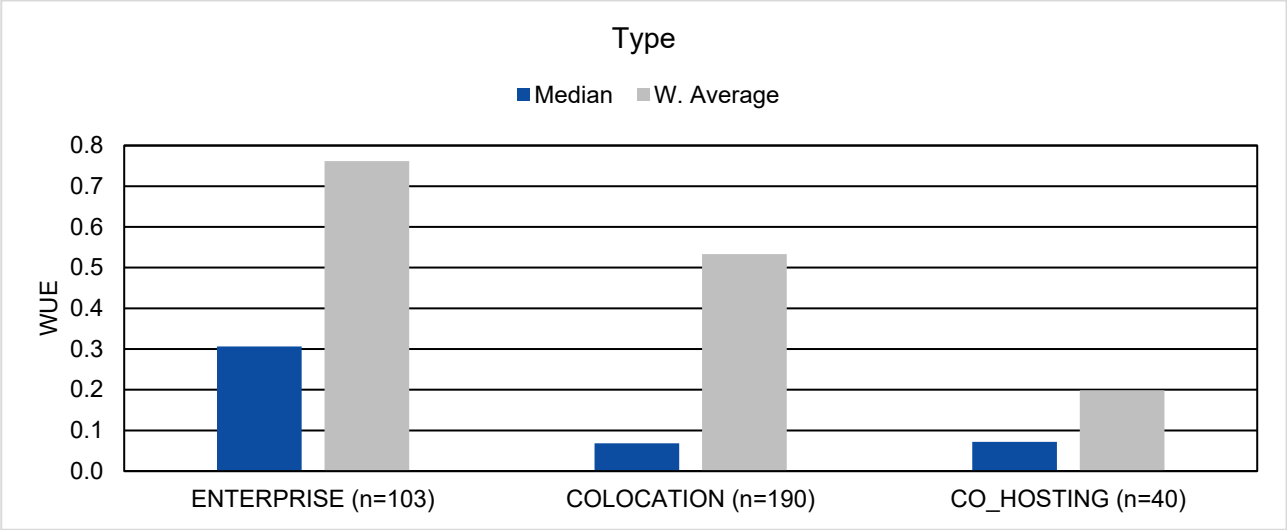
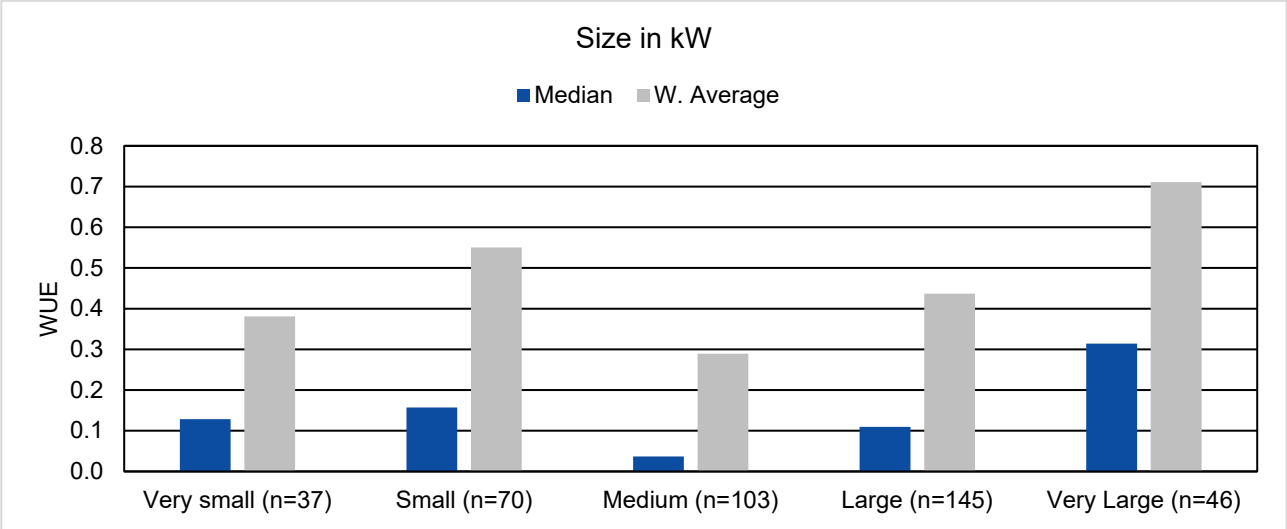


Figure 23 shows the WUE in relation to data centre size, measured by installed IT power in kilowatts. The size distribution is relatively balanced, with large data centres representing the biggest group at 100 entries. Across all size categories, the median WUE remains at or below 0.3 m³/MWh, with medium sized data centres showing the lowest values. Very small, small and very large data centres tend to have higher WUE values, both in terms of median and especially weighted average. For very small and small data centres, this can likely be attributed to their age, as a large share of them are older than ten years and may rely on outdated or less water-efficient infrastructure. In contrast, very large data centres may use advanced cooling technologies that are efficient in terms of energy but water-intensive, such as evaporative systems. The strong difference between median and weighted average in the small and very large categories further indicates the presence of a few high-consuming sites that significantly influence overall performance. This highlights the importance of addressing both ends of the scale, through retrofitting in small data centres and water-efficiency strategies in very large facilities.

Figure 23 - WUE in relation to Data Centre size in kW



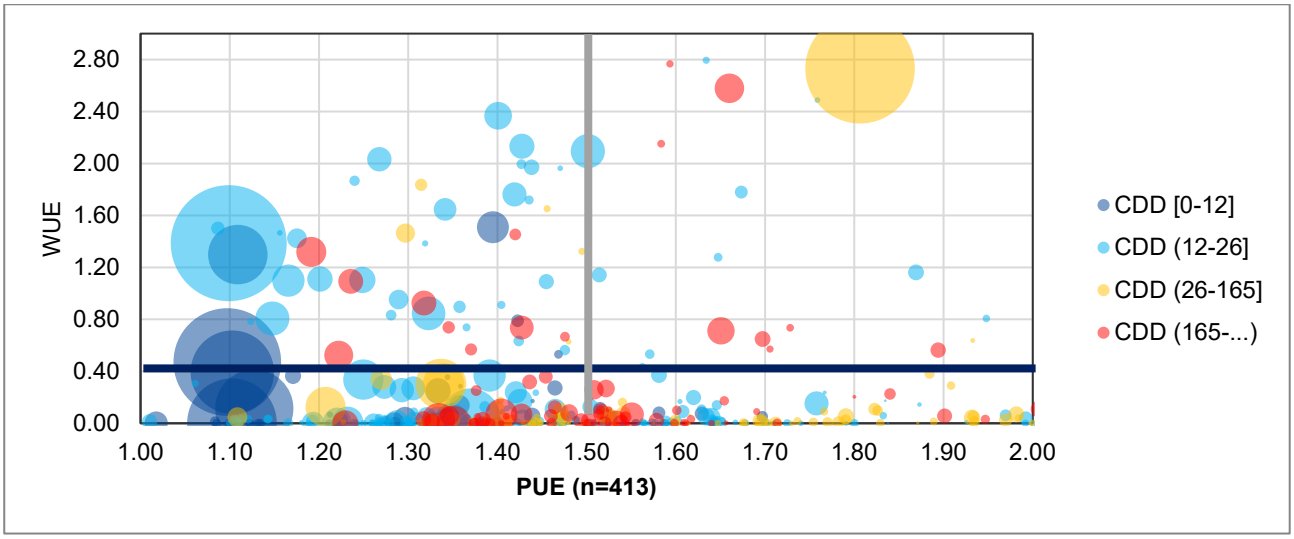
Summary on WUE:

In summary, the results show that WUE is influenced by a combination of factors including climate, age, size, type and reporting approach. While the median WUE remains below 0.3 m³/MWh across all categories, the weighted averages vary significantly and are often driven by a small number of large water-consuming data centres. Warm and moderate climate zones show slightly higher average WUE values, likely due to increased use of evaporative cooling, though detailed technology data is lacking. Data centres in the 4-to-6-year range exhibit higher weighted averages, suggesting a shift towards larger facilities with higher water needs. Enterprise-type data centres show the highest values overall, while co-hosting sites tend to remain low in both median and average terms. Differences by size are also visible. Very small and small data centres likely suffer from outdated infrastructure, whereas very large data centres tend to use water-intensive but energy-efficient systems. Overall, the findings highlight the importance of balancing PUE and WUE in future retrofit and planning strategies as well as encouraging consistent reporting practices to support comparability and informed decision-making.

PUE & WUE

Figure 24 below shows the relationship between PUE and WUE for 413 data centres. Each point represents one data centre, with circle size indicating installed IT power and colour representing the climatic zone based on CDD: blue tones correspond to colder climates, while red tones indicate warmer regions. Most data centres cluster in the area with low PUE (<1.5) (indicated in grey) and low WUE (<0.4 m³/MWh) (indicated in dark blue), suggesting generally efficient performance. Outliers are clearly visible across all climate zones. Notably, several larger data centres show a low PUE, combined with a high WUE, which could be related to increased use of evaporative cooling. While low PUE is achievable across all zones, warmer climates (yellow & red) show a broader spread in both metrics, reflecting the challenge of maintaining water and energy efficiency under higher cooling loads. This pattern aligns with earlier findings, where large data centres often perform well in terms of energy efficiency but show significantly higher water use.

Figure 24 - Relationship between PUE and WUE

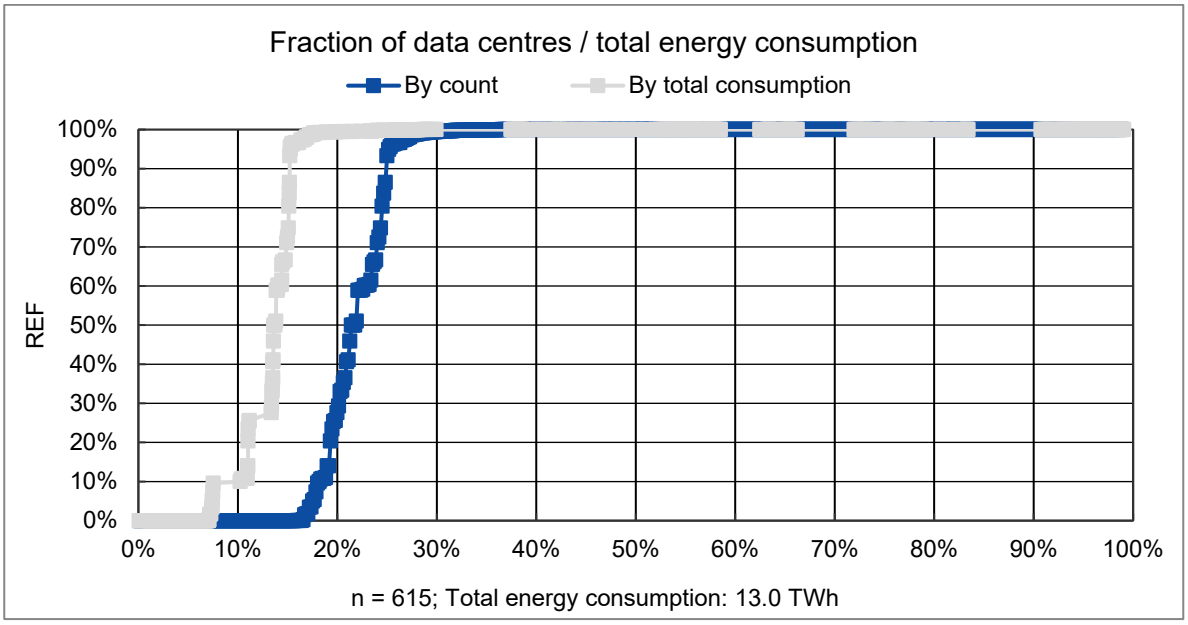


The observed correlation highlights that, while low energy consumption is achievable across all climate zones, maintaining both high energy and water efficiency becomes more challenging in warmer regions as well as for larger data centres. These results support the need for integrated cooling strategies that consider both PUE and WUE in parallel. In particular, water efficiency should be more closely monitored in large-scale facilities using water-intensive cooling technologies even if their energy performance appears optimised.

Renewable Energy Factor (REF)

The REF was calculated based on the reported total annual renewable energy consumption and the total annual energy consumption. Out of 748 entries, 614 entries with a total energy consumption of 13 TWh, provided correct data to caclulate the REF. Figure 25 below illustrates the REF based on the fraction of the number of data centres (blue) and the total energy consumption (gray). The weighted average REF across all data centres is 86.8%. Over 79% of the reported total energy consumed was covered by 100% renewable energy on an annual balance. Furthermore over 70% of data centres (by count) reported consuming 100% renewable energy on an annual balance through different means, including on-site renewables, guarantees of origin (GoOs) and power purchase agreements (PPAs). The vast majority of consumed renewable energy was backed by a GoO (around 70%) followed to a certain extent by PPAs (around 30%). Only a small fraction of renewable energy was produced on-site. A further analysis of the data centres below 100% REF did not reveal a clear dependency on age, size, type or climatic conditions. Therefore, no robust explanatory pattern could be identified.

Figure 25 - REF by count and by total consumption



Energy Reuse Factor (ERF)

The issue of reuse of waste heat from data centres is receiving increasing attention. Even as data centres become more energy-efficient and transition towards full decarbonisation, waste heat generation remains a constant factor. This makes strategic planning for the location of future data centres highly important. However, the potential for waste heat reuse depends heavily on local conditions, such as the availability of a district heating network and suitable consumers, as well as the surrounding area's actual heat demand.

Fifty data centres (approximately 8%) reported that they partialy reuse their waste heat, amounting to around 2% of the total available waste heat. The weighted average supply temperature of the reused heat was 25 °C, limiting its broader applicability without upgrading. A descriptive analysis of these data centres suggests that energy reuse occurs more frequently in smaller facilities and in enterprise-type facilities and is more common in colder climates. However, given the limited sample size and the overall low proportions, no robust, systematic trends could be identified. Therefore, the feasibility of heat reuse remains highly site-specific, and evaluation and setting of the ERF's MPS should primarily be carried out at a national or local level.

Nevertheless, there are several promising examples across Europe that demonstrate how data centres can successfully contribute to sustainable heating solutions:

- **Floridsdorf clinic (Austria)[44]**

In Vienna Floridsdorf, Digital Realty and Wien Energie use excess heat from Austria's largest data centre to cover up to 70 percent of the heating demand of the adjacent Floridsdorf clinic, saving about 4 000 tonnes of CO_2 per year.

- **WarmteStad (Netherlands)[45]**

[44]https://www.wienenergie.at/pressrelease/oesterreichs-groesstes-rechenzentrum-heizt-klinik-floridsdorf-startschuss-fuer-innovative-graetzl-heizung/

[45]https://qtsdatacenters.com/news/qts-groningen-data-center-first-to-supply-residual-heat-to-10000-households-buildings-and-knowledge-institutions/

In Groningen, QTS Data Centers and Bytesnet are collaborating with WarmteStad, to provide residual heat for a large-scale sustainable district heating project.

- **Digital Realty (Belgium)**[46]

In Brussels, the Digital Realty data centre supplies excess heat to warm local households through a new sustainable district heating project in Zaventem.

- **Stack Infrastructure (Norway)**[47]

In Oslo, Stack Infrastructure and Hafslund Oslo Celsio, have completed a joint project. The data centre is providing heat and hot water for up to 5 000 homes.

- **atNorth (Sweden)**[48]

The atNorth data centre in Kista is supplying the Stockholm district heating network with its residual heat. The residual heat from the data centre heats 20 000 apartments.

- **DC Avalon 3 (Italy)**[49]

In Milan, a2a, DBA Group, and Retelit are collaborating to transform the residual heat from DC Avalon 3 into thermal energy for 1 250 families.

- **ReUseHeat (Germany)**[50]

This project showcases a successful example of integration of the excess heat from an air-cooled data centre into the low-temperature district heating network of the city of Brunswick via an external CO_2 heat pump.

- **MODERATOR**[51]

This EU project aims at developing a novel, custom-designed immersion-cooling system using phase change materials to provide excess heat at 50-65°C.

- **THUNDER**[52]

This project aims at developing and demonstrating a seasonal thermal storage based on thermochemical materials coupled with a high-temperature heat pump for accumulation of excess heat (~60°C) during summertime and subsequent release into a district heating network (86°C) in winter.

- **Bytes2Heat**[53]

This project focuses on removing (especially) legal and commercial barriers in uptake of excess heat from data centres for heating applications. Tools and guidelines, e.g. for matching heat supply with demand, for calculating ROI, etc., are being developed, alongside the promotion of the best practices of innovative pilot projects.

[46] https://www.datacenterdynamics.com/en/news/digital-realtys-interxion-build-third-data-center-belgium/
[47] https://www.districtenergy.org/blogs/district-energy/2022/09/27/stack-data-centre-provides-excess-heat-for-oslo-ho
[48] https://www.atnorth.com/nordic-data-centers/sweden-data-centers/stockholm-metro-site/
[49] https://www.datacenterdynamics.com/en/news/retelit-to-use-waste-heat-from-milan-data-center-to-warm-1250-homes/
[50] https://www.euroheat.org/dhc/knowledge-hub/heat-recovery-from-data-centers-in-brunswick
[51] https://moderatorproject.eu/
[52] https://www.thunderproject.eu/project-summary/
[53] https://www.bytes2heat.com/

iv. Formulation of proposed MPS based on combined evidence

The objective of this sub-task was to formulate realistic and evidence-based MPS for data centres, based directly on reported data and in alignment with existing industry practices. To avoid additional administrative burden, the development of MPS relies soleley on the indicators already covered by the current reporting scheme. These include PUE, WUE and REF. All thresholds were derived from existing data entries and refined through stakeholder consultations and interviews with experts (see above).

The following section outlines potential MPS for data centres. These are put forward as input for further consideration. The intention is to support the legislative debate by illustrating technically and economically viable options that could contribute to the EU's energy and climate objectives. The thresholds proposed are in line with levels already discussed within the industry (e.g. CNDCP), which indicates that they are broadly accepted by stakeholders and already achieved by a majority of data centres according to the reported data. Transitional periods are foreseen to ease the adjustment process. The MPS are not meant to prevent innovation but rather to target mainly older and inefficient data centres that would in any case require renewal.

In order to avoid excessive reporting burden, emerging indicators such as CPU utilisation or workload-specific metrics (e.g. for AI/accelerated computing) are not included at this stage but could be explored in specialised models beyond the current MPS scope.

While MPS are viewed critically, they have been set at conservative levels that can be achieved with today's available technologies and should serve as baseline standards for new facilities. Naturally, they should also be subject to regular reviews and adaptation – as new data become available – and are explicitly designed to affect only persistently inefficient sites rather than limiting innovative or high-performance facilities.

To ensure credibility and comparability of the reported data, the basic reporting obligations under the Energy Efficiency Directive should be complemented by stronger governance and third-party verification. An additional MPS element could be a mandatory third party verification of selected KPIs or sustainability plans to ensure data quality and comparability This could include harmonised EU-wide data validation, randomised audits and independent checks by accredited organisations, such as certification bodies or auditors. Such measures would improve data quality, create a level playing field and avoid unnecessary administrative burden for operators.

The following aspects are considered particularly relevant for the definition of MPS and are accompanied by concrete recommendations for their implementation.

Climate Normalisation

Several stakeholders highlighted the need for climate normalisation of the KPIs to create a level playing field. This could be achieved using the already reported Cooling Degree Days (CDD) and the cooling technologies applied, which are not yet reported (but highly recommended). However, around 22% of the reported CDD values were considered incorrect.

For this reason, the chosen MPS values have been set at levels that are considered achievable across all European climate zones. To address these inconsistencies in the CDD reporting, it is recommended to follow a two-step approach. As a first step, guidelines should provide a direct link to reliable NUTS3-based CDD data (e.g. Eurostat[54]), ensuring that operators can reference correct values without additional calculation. As a second step, CDD data collection should be automated by translating reported locations into NUTS3 regions and retrieving the correct CDD values directly

[54] Eurostat (2024). Cooling and heating degree days by NUTS 3 region – annual data. Available at: https://ec.europa.eu/eurostat/databrowser/view/NRG_CHDDR2_A__custom_2773291/bookmark/map?lang=en&bookmarkId=d51ebdbf-21db-44c5-a50b-32b99b892ca1 & https://ec.europa.eu/eurostat/databrowser/view/nrg_chddr2_a/default/table?lang=en&category=nrg.nrg_chdd

from Eurostat or comparable public sources. This would reduce reporting and calculation burdens and avoid errors such as using one national average for all facilities (as observed for Germany).

After implementation, a re-valuation of the influence of climate on results is strongly advised. Further refinements may be considered after two full reporting cycles will have been completed to ensure sufficient data robustness.

Proposed thresholds for PUE

Out of 748 reported entries, 600 provided both the total energy consumption and the total energy consumption of the IT equipment to derive the PUE. Based on these entries, an operational PUE target of < 1.5 by 2030 for existing data centres (i.e. commissioned before 2027) may serve as a technically achievable and progressive benchmark. For data centres commissioned from 2027 onwards, a design PUE < 1.3 may be considered, based on the best-practice examples already implemented today. Considering an operational ramp-up period, an operational PUE < 1.4 could be targeted within three years of operation. This reflects both current performance levels and the ambition expressed by stakeholders.

- Operational PUE < 1.5 for existing data centres (i.e. commisioned before 2027) by 2030: Achievable for most existing sites based on current dataalso considering a retrofit period
- Design PUE < 1.3 for new data centres commisioned from 2027: Reflects high-performing new builds already in use.
- Operational PUE < 1.4 for new data centres commisioned from 2027 within three years of operation: Accounts for realistic ramp-up period.

The thresholds have been defined to ensure they are realistically achievable across legacy, existing and new facilities based on the provided data. Notably, 56% of reported entries (n=600) already achieve a PUE ≤ 1.5 today, including 49% of entries older than ten years (n=390) and 46% of entries with CDD>165 (n=98), which demonstrates that the proposed threshold is both realistic and ambitious. Given that almost half of the sites in the hottest climate zones already reach this level today, it is reasonable to expect that, with further efficiency gains and retrofits, the great majority will be able to comply by 2030. This aligns with stakeholders' expectations for progressive but technically feasible benchmarks. Further segmentation may be considered in future reviews as more robust data becomes available.

Proposed thresholds for WUE

Out of 748 reported entries, 421 provided both the total water input in m³ and the total energy consumption of the IT equipment to derive the WUE. Since cooling methods were not reported, it was not possible to verify whether a reported value of 0 m³ indicated missing data or an actual value. Therefore, entries with WUE = 0 were excluded from this evaluation. For water use, a WUE threshold of < 0.4 m³/MWh could be introduced as a benchmark for all data centres, regardless of climate or cooling technology. This value aligns with the CNDCP recommendations and is already met by many small and large operators, even under challenging conditions. For consistency and comparability, only WUE values reported under Category 2 (net water input) should be considered, taking into account a transition period until 2030. Survey results from the fourth workshop support this approach: 87% of respondents favour exclusive use of Category 2 reporting, while only 9% see the effort as disproportionate.

- WUE < 0.4 m³/MWh for existing data centres by 2030: Already met by many operators, even in warm climates.
- WUE < 0.4 m³/MWh for new data centres commissioned from 2027: Promotes best-practice adoption and supports investment planning.

- Category 2 reporting only by 2030: Enables harmonised data and comparability.

Notably, 72% of reported entries (n=421) already achieve a WUE ≤ 0.4 today, including 74% of entries older than ten years (n=270) and 67% of entries with CDD>165 (n=79).The calculation of Water Usage Effectiveness (WUE) could be further expanded to include water depletion since usage thresholds must reflect local conditions. Local water depletion at NUTS3 level can be obtained, for example, from the freely available geodata from Aqueduct of the World Resources Institute[55]. The reported location of data centres could be translated into the NUTS3 region and the highest value from current and 2050 scenarios would be applied. In such a case, a threshold of 25 percent water depletion is proposed. For locations with water depletion below 25 percent, no or only less strict EU-wide requirements are recommended. In such cases, national regulations should apply where necessary and feasible. For locations with water depletion above 25 percent, WUE is recommended to be below 0.4 m³/MWh for all data centres by 2030 and for new data centres from 2027 onwards with additional focus on WUE regardless of the water source. Based on the feedback from the workshop, approximately 75% of respondents generally support WUE requirements with a majority favouring a uniform EU-wide value.

Proposed threshold for REF

Out of 748 entries, 608 provided correct data to calculate the REF. With regard to renewable electricity sourcing, the data shows that 79 % of total reported consumption and over 70 % of data centres already operate on 100 % renewable energy (annual balance), primarily through Guarantees of Origin and Power Purchase Agreements. The weighted average REF across all reported data is 86.8 %. Based on this, the consortium proposes a target of 100 % renewable electricity on an annual basis by 2030 through different means of acquisition. For future reporting, an additional field to report the share of hourly-matched renewables is recommended to evaluate the current share and to provide a basis for expanding MPS towards hourly matching in the future.

- REF = 100 % by 2030: Already common practice among major operators. Attention should be increasingly paid to the quality, source and additionality of renewables used, as well as the temporal matching of supply and demand.

Consideration of ERF and Local Context

The analysis confirms that while waste heat from data centres holds considerable potential for contributing to decarbonisation in district heating and industrial applications, its practical implementation depends strongly on local infrastructure and heat demand. Out of 748 entries, 617 provided correct data to calculate the ERF. Only 50 out of 617 data centres reported any reuse of residual heat, with an average waste-heat outlet temperature of 25 °C. As a result, the consortium does not recommend introducing a uniform EU-wide MPS for the ERF at this stage.

Instead, the ERF should be assessed and regulated at national or local level, where technical feasibility and economic viability can be determined in context. One possible approach could be the definition of a location-specific “maximum possible ERF” (MaxERF) by local authorities, reflecting the share of waste heat that can realistically be reused under local circumstances over a defined time horizon (e.g. 10 years). For regions where all waste heat could theoretically be reused, MaxERF would equal 100%. The MPS related to ERF for each data centre could then be expressed as the ratio of actual ERF to MaxERF. This allows for a quick assessment of whether (i) all local reuse options are considered (ERF/MaxERF = 1), or (ii) no reuse is implemented despite available options (ERF/MaxERF = 0). If no feasible reuse option exists (MaxERF = 0), the indicator should be reported as “not applicable (N/A)”, with siting criteria or planning obligations applied separately. To ensure comparability and avoid unintended incentives, MaxERF determination should follow a standardised methodology (criteria including temperature level, distance to networks/off-takers, economically justified demand, CAPEX/OPEX) and be reviewed periodically (e.g. every 3 years). Authorities are

[55] https://www.wri.org/aqueduct

encouraged to define specific targets where regional heating networks and off-takers exist or are planned for expansion or new development in the future. Several successful pilot projects (e.g. ReUseHeat, THUNDER, MODERATOR) demonstrate the potential of coordinated planning and innovation in this area.

However, under the Energy Efficiency Directive (EU) 2023/1791[56], a cost-benefit analysis (CBA) of heat reuse must be carried out for new or substantially refurbished data centres above 1 MW, and technical provisions such as heat exchangers or network interfaces must be implemented where the CBA demonstrates technical and economic feasibility. While this does not yet constitute a uniform MPS across the EU, it effectively introduces a conditional 'heat reuse readiness' requirement for new larger data centres. In practice, compliance with this requirement implies that provisions for connection points, space for heat exchangers and pumps, and adequate measurement and control interfaces should be foreseen already at the design stage for new data centres and at the planning stage for major refurbishments.The additional investment for such readiness measures is typically modest if planned from the outset, yet operators may still perceive it as disproportionate in locations without nearby heat demand. Policymakers could therefore consider targeted support or apply the obligation mainly in regions where district heating expansion is foreseen, in order to balance feasibility with cost-effectiveness. Furthermore, policymakers should implement measures (incentives, land-use restrictions, etc.) to encourage operators to situate new data centres in locations with a nearby heat demand, or where heat demand or a district heating network is expected to develop in the near future.

Summary on MPS

In summary, the proposed MPS represent a pragmatic first step towards harmonised EU-wide standards for data centre efficiency. They are deliberately set at conservative levels that can already be achieved with today's technologies, providing a baseline requirement for persistently inefficient sites while leaving room for innovation and more ambitious voluntary initiatives. Given the limited data quality of the first reporting cycle, the thresholds should be reviewed and, if appropriate, adjusted after approximately three years, once two full reporting cycles provide a more robust evidence base. In this way, the proposed MPS establish a credible foundation that can be progressively strengthened over time, guiding investment and policy decisions while supporting the EU's broader climate and energy objectives.

v. Integration of BATs and feasibility assessment

BAT overview and Rating

To support the proposed MPS, the assessment of Best Available Techniques (BATs) builds directly on the methodological framework described in section 2 sub-section ii and on findings of the DCESS[57] project. A comprehensive catalogue of BATs was compiled and scored against the four KPIs: PUE, WUE, REF, and ERF. Each measure was evaluated for impact potential (scale –5 to +5 for each KPI) and for implementation-related criteria, such as technical maturity, payback time, organisational effort, and implementation risk (scale 1 to 5). Weighting of these criteria ensured that both effectiveness and feasibility were reflected in the final score. The assessment also tested applicability across 27 archetypes of European data centres reflecting different sizes, ages, and climate conditions.

The results of this assessment offer guidance for data centres and policymakers on how targets can be realistically achieved. The full rating can be found in Annex 2. Table 7 presents the highest-scoring BATs per KPI:

[56] Energy Efficiency Directive (EU) 2023/1791
[57] https://www.borderstep.org/projekte/optimising-synergies-between-data-centres-and-energy-systems/

Table 7 - Overview of the highest-scoring BATs (Note: Individual scores are weighted values based on the KPI impact from –5 to +5 and on the implementation criteria from 1 to 5, where higher values indicate stronger overall performance)

KPI	Measure	Weighted Score	Description / Impact
PUE – Improve Energy Efficiency	Immersion Cooling	3.3	IT components are submerged in dielectric fluid increasing heat transfer and consequently the cooling efficiency. Significant energy savings and higher potential for waste heat reuse due to higher waste heat temperatures.
	Cold-/Hot Aisle Containment	3.3	Prevents mixing of cold and hot air by separating airflow zones. Improves cooling efficiency and requires relatively low retrofitting effort.
WUE – Reduce Water Consumption	Dry Adiabatic Cooling Systems	3.1	Uses dry air-cooling most of the time and spraying of water only during peak loads. Strong reduction in water consumption compared to wet cooling towers.
	Free Cooling with Filtration	2.9	Uses filtered outdoor air for cooling, reducing or eliminating water use. Most effective in, cold to moderate climates where ambient temperatures frequently allow substitution of mechanical cooling.
REF – Increase Renewable Energy Use	Power Purchase Agreements (PPAs)	2.45	Long-term contracts for renewable energy supply. Widely used and financially effective.
	On-Site PV	2.35	Solar panels installed on-site provide direct renewable energy. Contribution limited by space and typically covers only a fraction of demand.
ERF – Enable Waste Heat Recovery (Sources)	Waste Heat Recovery via Heat Pump	2.2	Recovers thermal energy from cooling circuits using heat pumps. Adds electricity demand but enables the reuse of waste heat, e.g. for district heating or nearby consumers such as hospitals.
	Direct-to-Chip Cooling	2.2	Extracts high-quality waste heat directly from IT equipment. Requires integration into reuse systems.
ERF – Enable Waste Heat Recovery (Sinks)	Low-Temperature Heat to Agri-Tech	2.45	Supplies heat to greenhouses or hydroponics. Continuous demand with low temperature requirements.
	Healthcare Applications	2.4	Provides stable demand for sterilisation, heating and hot water in hospitals and clinics. Requires proximity to healthcare facilities.

These individually assessed BATs provide practical pathways for data centres to improve performance and comply with proposed MPS. By combining technical feasibility with operational insights, they form a solid basis for guiding investment decisions, policy incentives, and future regulation.

BAT Rating applicability and effect of BATs under realistic conditions

To test the applicability of BATs under realistic conditions, the archetypes described in chapter 2.a.ii, Table 16 and Table 17 have been used. The evaluation of the BATs based on these archetypes was

carried out using expert judgement and literature review and may not reflect actual conditions in data centres. It is intended to provide an indication of the potential impact of the BATs. The selected values should be understood as indicative ranges that illustrate possible orders of magnitude under different climatic and technical conditions rather than exact predictions for individual data centres. Furthermore, a more detailed techno-economic analysis would be necessary for an accurate assessment and no decisions should be based solely on this evaluation.

Based on the highest-rated BATs, six implementation scenarios were developed and applied across the 27 data centre archetypes. In each case, a single measure was integrated into the existing archetype configuration to estimate its potential impact on relevant operational fields such as cooling, ventilation, water use, IT energy demand, UPS load, and REF.

1. **Immersion cooling & waste heat reuse with a heat pump (linked to a healthcare facility):**

This scenario combines immersion cooling, a heat pump (COP 3) and a hospital as heat consumer. Partnership between hospitals and data centres is already a best practice[58]. Across all 27 data centre archetypes, it is assumed that electricity demand for cooling and ventilation can be significantly reduced and water use can be largely avoided. This is because immersion cooling eliminates the need for traditional air-based cooling and drastically reduces airflow requirements, while also removing the need for water-intensive chillers or cooling towers. IT load remains unchanged. Additional electricity demand may occur depending on the size and configuration of the heat recovery system.

With this measures, heat reuse is possible in the data centres, as immersion cooling can provide a stable heat source, ideal for healthcare use with a constant demand. Smaller centres benefit from a higher relative recovery, larger ones from a higher absolute heat volume. PUE can be improved especially in older data centres, WUE is expected to improve considerably and REF can also show improvements due to reduced overall electricity needs. The measure offers strong potential for improving energy and resource efficiency, especially where consistent heat demand exists. Table 8 provides an overview highlighting archetypes where the measure is likely to have the strongest effect, particularly in older, small to medium data centres and in low to medium CDD.

Table 8 - Effect of measure 1 "Immersion cooling & waste heat reuse with a heat pump" on different KPIs in archetypes with highest expected impact

Archetype	PUE	WUE	ERF	REF
Old/Low CDD/Small	-18%	-95%	New heat reuse	+22%
Old/Medium CDD/Small	-15%	-95%	New heat reuse	+18%
Old/Low CDD/Medium	-14%	-95%	New heat reuse	0%
Old/Medium CDD/Medium	-13%	-95%	New heat reuse	+15%
Old/High CDD/Medium	-13%	-95%	New heat reuse	+14%
Old/High CDD/Small	-10%	-95%	New heat reuse	+11%

2. **Power Purchase Agreement (PPA):**

The effect of PPA on the REF and its potential improvement is dependent on economic factors and electricity demand of the data centre. Therefore, it is not possible to directly evaluate the improvement in the REF. Although REF could theoretically reach 100%, a more detailed techno-economic analysis would be required to assess the feasibility, especially if 24/7 hourly matching is

[58] https://www.digitalrealty.at/resources/articles/sustainable-partnership-digital-realty-vienna-and-klinik-florisdorf-go-hand-in-hand

to be considered. The main effect of PPA is on the energy sourcing, without technical infrastructure changes.

3. On-site photovoltaic (PV) generation:

On-site renewables are often limited by the available space or regulatory requirements. Even tough on-site power mostly accounts for only a fraction of the energy demand, available areas should nevertheless be utilised when techno-economically feasible. For this evaluation, a server power density of 2.5 kW/m² was assumed, with a rooftop area 100% covered with PV

equivalent to the server floor area[59]. Solar yields are assumed based on the CDD[60]:

- 1 400 kWh/m²/year (high CDD),
- 1 000 kWh/m²/year (medium CDD)
- and 800 kWh/m²/year (low CDD).

For data centres whose REF is not yet 100%, the potential share of renewable energy from rooftop PV is estimated, along with the resulting REF improvement. Table 9 outlines the five archetypes, where PV most likely has the most effect.

Table 9 - Effect of Measure 3 "On-site photovoltaic (PV) generation" on REF in archetypes with highest expected impact

Archetype	REF Before	REF After
Old/Low CDD/Large	20%	36%
New/Medium CDD/Small	35%	48%
Average/Low CDD/Medium	54%	64%
Old/Medium CDD/Medium	74%	83%
Average/Medium CDD/Small	44%	53%

4. Cold-/Hot aisle containment:

Cold or hot aisle containment involves physical separation of cold and hot airflows within the data hall, reducing mixing losses and increasing the thermal efficiency of the cooling system. This measure is applied across all existing data centre archetypes and delivers its strongest effects in older facilities with conventional air-based cooling such as CRAC or CRAH systems. The containment improves airflow control, allowing for higher return temperatures and reduced fan speeds. As a result, cooling energy demand can be noticeably reduced depending on system type and climate. Ventilation energy may also decrease due to lower required airflow volumes, while water use can be reduced in systems using chilled water or adiabatic components.

The greatest efficiency gains can typically be expected in older, small to medium-sized data centres across different CDD zones (see Table 10). These facilities benefit the most from improved airflow separation due to previously inefficient ventilation layouts. In contrast, modern data centres with in-row, rear-door, or liquid cooling systems already feature optimised air paths and are expected to benefit less from containment. Overall, containment is a well-established, low-disruption retrofit measure with proven benefits across energy, water, and system stability.

[59] Pelda Johannes, Reuter Stefan, Cozzini Marco, Gebetsroither-Geringer Ernst, Salaymeh Abdulraheem, Paradiso Rosanna, Holler Stefan (2023): Advanced algorithm for spatial identification, evaluation of temporal availability and economic assessment of waste heat sources and their local representation. IEA DHC/CHP Report, 2023.

[60] https://re.jrc.ec.europa.eu/pvg_tools/en/

Table 10 - Effects of Measure 4 "Cold-/Hot aisle containment" on different KPIs in archetypes with highest expected impact

Archetype	PUE	WUE	REF
Old/Low CDD/Small	-7%	-15%	+8%
Old/Low CDD/Medium	-6%	-15%	0%
Old/High CDD/Medium	-5%	-10%	+5%
Old/Medium CDD/Medium	-5%	-10%	+5%
Old/Medium CDD/Small	-5%	-8%	+5%

5. Dry adiabatic cooling systems:

Dry adiabatic cooling systems involve replacing conventional cooling technologies with air-based systems that pre-cool intake air through adiabatic processes without significant water consumption. This scenario assumes full retrofitting across all 27 data centre archetypes. The measure is particularly effective in hot climates and small, air-cooled facilities, where existing CRAC or CRAH systems are inefficient and water-consuming. Water use can be significantly reduced, especially in small archetypes that rely heavily on mechanical or evaporative systems. At the same time, cooling electricity demand can be lowered and ventilation energy may also decrease due to lower airflow requirements. The highest relative savings can usually be achieved in small and older facilities that are more dependent on basic air cooling (see Table 11). Medium-sized data centres also benefit, particularly when operating chilled water or in-row systems that respond well to reduced intake temperatures. Large facilities, although already more efficient, can still achieve some improvements in energy and water use. Dry adiabatic cooling is most impactful in air-based setups and offers a technically simple yet highly effective measure to reduce both operational cost and environmental footprint.

Table 11 - Effects of Measure 5 "Dry adiabatic cooling systems" on different KPIs in archetypes with highest expected impact

Archetype	PUE	WUE	REF
Old/Low CDD/Small	-7%	-90%	+7%
Old/Medium CDD/Small	-6%	-90%	+6%
Old/High CDD/Medium	-5%	-80%	+6%
Old/Low CDD/Medium	-5%	-85%	0%
Old/High CDD/Small	-5%	-85%	+5%

6. Free cooling with filtration:

This measure assumes the integration of filtered free cooling in existing data centres, enabling the use of outdoor air in suitable climates to reduce reliance on compressor-based mechanical cooling (e.g. chillers or conventional air conditioning systems). In contrast to mechanical cooling, where heat is removed using compressors and refrigerants, free cooling uses outside air directly, only filtered to maintain air quality, to provide part or all of the cooling demand. The effectiveness of this approach varies significantly depending on system type, climate zone and facility size. Free cooling is most beneficial in low to moderate CDD regions, where ambient temperatures often allow for partial or full substitution of active refrigeration systems. Potential benefits mainly relate to reduced electricity use for cooling and, depending on the system, lower water demand, while ventilation energy may slightly increase due to additional air resistance from filters. Table 12 illustrates typical archetypes where the impact is expected to be most noticeable, particularly in small to medium-sized, older or average-aged facilities in low CDD climates. Overall, free cooling with filtration is a low-impact, high-compatibility measure that can provide moderate gains in energy and water efficiency, especially in

retrofitted facilities in colder zones. Its main benefits lie in operational savings and environmental performance, with minimal infrastructure disruption.

Table 12 - Effects of Measure 6 "Free cooling with filtration" on different KPIs in archetypes with highest expected impact

Archetype	PUE	WUE	REF
Old/Low CDD/Small	-4%	-18%	+5%
Average/Low CDD/Medium	-4%	-18%	+4%
Average/Low CDD/Small	-4%	-20%	+3%
Old/Low CDD/Medium	-3%	-15%	0%
Average/Medium CDD/Small	-3%	-15%	+3%

Each scenario serves to illustrate the possible efficiency or sustainability gains from targeted BAT implementation. However, in-depth site-specific assessments would be required to determine actual feasibility and performance.

Overall, the assessment indicates that BATs can make a meaningful contribution across all key performance indicators, with the strongest effects in older and smaller data centres. For policy and decision makers, this suggests that supporting a mix of retrofitting measures (e.g. containment or adiabatic cooling) together with energy sourcing strategies (e.g. PPAs or PV) is likely the most effective pathway. While exact impacts will always depend on local conditions, the analysis provides a structured basis for prioritising measures and identifying where regulatory incentives or standards could be most impactful.

c. Task 2.3 – Assess the feasibility of a transition towards a net-zero emission data centre sector

i. The general understanding of net-zero in the data centre context

This chapter is dedicated to the question of what a transition to a net-zero emission data centre sector means, how it could be achieved and whether it is feasible. However, the first step is to gain a clear understanding of what the term "net-zero emissions" means.

There are various definitions of net-zero emissions or climate net-zero. The term 'net' generally means that emissions do not necessarily have to be avoided, but at least compensated by other measures, which means that considering all factors, there is no impact of a company or in this case a whole industry sector on the warming of the climate. The "net" can also be understood as an acknowledgement that an absolute reduction of greenhouse gas emissions to zero is not possible or at least can only be achieved with enormous technical or economic effort.

It is quite common, that measures to offset emissions are not provided by the emitting companies themselves, but by others and can be purchased in the form of certificates. Usually such certificates are issued, where GHG emissions are actively avoided, reduced or removed from the atmosphere.

The idea behind such certificates is, that action is taken first where it will have the greatest positive impact on the climate at the lowest cost. Emitters that find it very difficult to reduce their emissions pay other companies or initiatives to implement measures with the corresponding amounts of CO_2 equivalents in emission reduction or carbon removal. In addition, in recent years the discussion surrounding carbon dioxide removal (CDR) has gained importance.

Particularly in growth industries with large margins, it can be more lucrative for players to offset emissions through certificates rather than adapting their own production processes to reduce emissions and switching to more climate-friendly products (Scope 2 + Scope 3).

In terms of the feasibility of achieving net-zero emissions in the data centre sector until 2030, a key question is how much emissions must be reduced, and which can be offset by certificates.

The Intergovernmental Panel on Climate Change (IPCC) recommends the use of CDR but also states that it is not a substitute for deep emission reductions.[61] It therefore seems sensible to continue to focus on emission reduction in the emitting sectors and only allow the last, non-reducible or difficult-to-reduce emissions through such compensation mechanisms. Also, the Science Based Targets Initiative focuses primarily on emissions reduction and does not allow carbon offsets to count towards the achievement of targets.[62]

Even within the climate targets defined by the EU, there are various mechanisms that explicitly aim at immediate emission reductions, such as the Fit-for-55 package, the tightening of the EU Emissions Trading System, actual emission targets for cars and buildings (EPBD), and energy efficiency improvements within the Energy Efficiency Act.

While reducing emissions often requires difficult, costly and lengthy processes for many existing industries and, for example, the building sector, large parts of the digital infrastructure are only just being built up or are being expanded. Further enormous growth is also expected in the coming years, partly due to the boom of generative AI.[63]

There are good reasons to set ambitious targets early on in this sector and to set the course directly for minimal emissions and integration into a climate-neutral economic system. Subsequently, due to the high demands placed on the continuous operation of data centres, it will no longer be possible to make changes to key factors for sustainability such as cooling systems, power supply and the location of a data centre (e.g. for waste heat utilisation or replacement of the refrigerant), or it will be much more difficult than in other industries.

ii. Different types of greenhouse gas emissions of the data centre sector and how to reduce them

To assess what net-zero emissions mean for the data centre industry and to what extent a real reduction of these emissions is feasible, a good understanding of data centre emissions is necessary. However, a major challenge is that, despite the reporting requirements of the EED and the Delegated Act, there is very little information available on emissions other than those from the main emission area of 'energy use in operation'.

Aslan et al. (2025)[64] are discussing the trends towards climate-neutral data centres and the difficulties in assessing the status (especially regarding scope 3 emissions) and the challenges with GHG reporting in the industry. For a general understanding of the distribution of emissions of the data centre sector, an example lifecycle-based assessment of GHG emissions for a data centre in Germany by Borderstep Institute (see Figure 26) can be used as reference.[65] Emissions of the end-of-use were not covered in this case. This was calculated on a location-based energy mix in Germany in 2023 of 0.445 kg of CO_2 per kWh (including upstream emissions, e.g. for production of solar panels etc.). The high proportion of greenhouse gas emissions attributable to energy consumption (in this

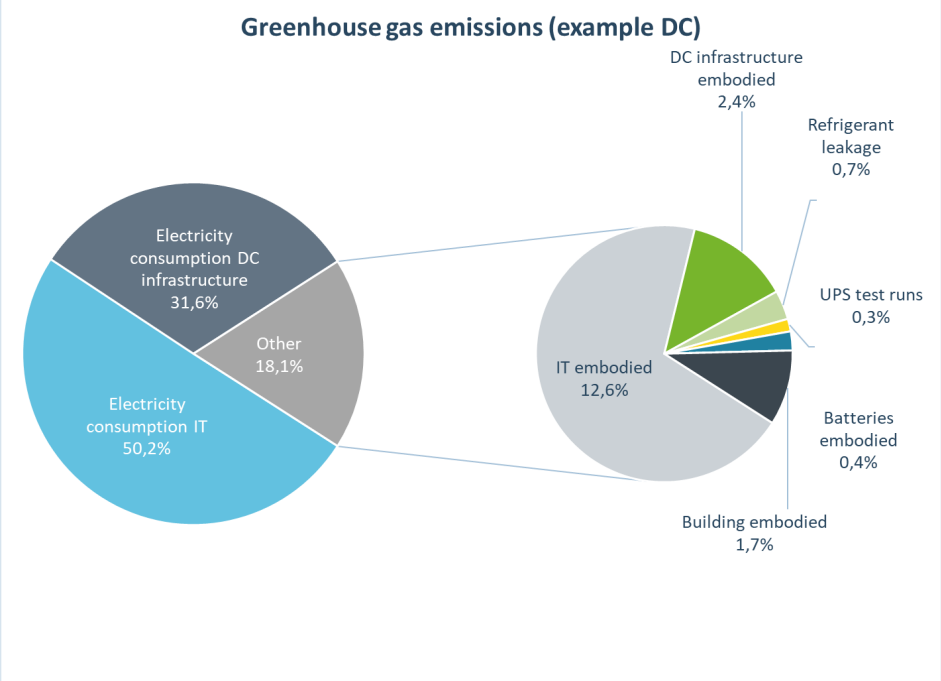
[61] https://www.ipcc.ch/report/ar6/wg3/downloads/outreach/IPCC_AR6_WGIII_Factsheet_CDR.pdf
[62] https://files.sciencebasedtargets.org/production/files/Net-Zero-Standard.pdf
[63] IEA. (2025). *Energy and AI – Analysis*. IEA. https://www.iea.org/reports/energy-and-ai/energy-demand-from-ai
[64] Aslan, T., Holzapfel, P., Stobbe, L., Grimm, A., Nissen, N. F., & Finkbeiner, M. (2025). Toward climate neutral data centers: Greenhouse gas inventory, scenarios, and strategies. *iScience*, *28*(1). https://doi.org/10.1016/j.isci.2024.111637
[65] This is a result of a very detailed LCA analysis of a specific data centre in Germany; also used in BMWK (2025). *Stand und Entwicklung des Rechenzentrumsstandorts Deutschland. Gutachten im Auftrag des Bundesministeriums für Wirtschaft und Klimaschutz*. BMWK. https://www.bmwk.de/Redaktion/DE/Publikationen/Technologie/stand-und-entwicklung-des-rechenzentrumsstandorts-deutschland.pdf?__blob=publicationFile&v=10 (p. 46)

example >80%) shows how crucial the energy use is and, consequently, how much emissions can vary between different member states simply due to differences in their electricity mix.

Because of the importance of the energy-based emission, already in 2020, the EU Commission published a report[66] which calculated that energy-based emissions of data centres will reach 3.2 % of the final electricity demand in the EU in 2030 and has used this number in various strategic goals, including the Delegated Regulation 2024/1364.[67]

Other emissions generated during the operation of a data centre are mainly caused by refrigerant leaks and test runs of emergency diesel generators. Considering the whole lifecycle, like the manufacture of IT hardware, building technology (cooling, UPS, lighting, etc.) and the construction of the building, these do also cause greenhouse gas emissions. Their shares appear relatively small in the example below, with embodied emissions in IT equipment at 12,6%, data centre infrastructure at 2,4% and building and batteries together at 2,1%. However, if a data centre is located in a country with a very low carbon intensity in its electricity mix or purchases low-carbon electricity, these ratios of embodied emissions can grow to a much bigger size.

Figure 26 - GHG emissions of an exemplary data centre in Germany based on own calculations[68]



iii. Feasibility of net-zero emissions and specific emission reduction potentials for different GHG emission categories

GHG emissions of electricity

The electricity consumption of IT equipment and the data centre infrastructure are in most cases the biggest share of the energy consumption of data centres. Although there have been massive

[66] Hintemann, R., Hinterholzer, S., Montevecchi, F., & Stickler, T. (2020). *Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market*. Borderstep Institute & Environment Agency Austria. https://digital-strategy.ec.europa.eu/en/library/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market

[67] Commission Delegated Regulation (EU) 2024/1364 of 14 March 2024 on the First Phase of the Establishment of a Common Union Rating Scheme for Data Centres, Pub. L. No. EU) 2024/1364. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401364

[68] GHG emissions calculated on the actual inventory of a real data centre in Germany over a whole life cycle

efficiency gains in the ICT equipment[69], the growing demand for compute, storage and networking resources keeps the energy demand of devices like servers at the same level and is in many cases even rising. Also in total amounts of whole countries, continents and globally, the energy demand of IT equipment is rising.[70] In the data centre infrastructure (cooling, UPS, light etc.), there are slow but steady improvements which are reflected by improving PUE, with average of 1.36 (see first technical report of this study[71]) or around 1.54 when looking at a global level including smaller data centres.[72] Especially the type and configuration of the cooling systems have a huge impact, with modern systems especially in large well-maintained data centres outperforming many older systems.

The emissions caused using this electricity, both for IT equipment and infrastructure, is highly dependent on the energy production mix and thus the emission allocation method. There is a general difference between calculating the emissions of data centres based on the national energy mix and calculating the emissions from a specific electricity contract, which can state a carbon intensity as low as 0 g/kWh depending on whether upstream chains are considered or not.

It is certainly worth discussing whether guarantees of origin (GoOs) can be considered sufficient to certify the climate neutrality of the electricity that is used. These guarantees allow, for example, the same amount of energy to be generated at any location at any time of the year as a data centre consumes at another location at another time. Although electricity is not a physical product, its transport over long distances and storage in large quantities represents a significant additional expense and leads to losses. Similarly, in the case of GoOs, the electricity may come from old, long-depreciated hydroelectric power plants and thus does not necessarily lead to investment in new low-carbon power generation. Particularly in view of the massive restructuring of the electricity supply in Europe and new challenges posed by the volatile nature of wind and photovoltaic-based power generation, GoOs are not sufficient to support all necessary steps (including storage, demand-side flexibility and power grid expansion or more local generation structures) for long term and system-wide decarbonisation.

With green Power Purchase Agreements (PPAs) in contrast, it can at least be guaranteed, that new production facilities (usually Wind or Photovoltaic) are being built up. However, PPAs also differ fundamentally and can either generate electricity directly at the point of consumption (physical PPA) or off-site with balance sheet delivery (virtual PPA). Off-site PPAs can then be further differentiated depending on whether a data centre operator, for example, simply purchases the generation profile from a producer (e.g. wind farm) and takes care of the rest themselves (e.g. procuring residual electricity when there is no wind) or whether this task lies with the PPA provider (sleeved PPA).

In all cases, there may be agreements or guarantees between electricity consumers and suppliers that the electricity is to be generated from CO_2-free sources, for example, in a spatial context (e.g. market area/control area) and/or in a temporal context (quarterly, hourly, etc.) in relation to consumption. Nevertheless, such agreements sometimes involve considerable additional expense for the provider, which is why they have hardly been implemented to date. However, some studies have shown that precisely such ambitions for system-wide decarbonisation and innovations for flexibility in the energy system could be the key[73].

[69] Coroamă, V. C., Hinterholzer, S., Dumbravă, O., & Hintemann, R. (2025). *Energy Efficiency of Servers*. Roegen Centre for Sustainability & Borderstep Institute. https://www.borderstep.de/wp-content/uploads/2025/06/EDNA-EE-of-servers-FINAL.pdf

[70] Shehabi, A., Smith, S., Hubbard, A., Newkirk, A., Lei, N., Siddik, M. A. B., Holecek, B., Koomey, J., Masanet, E., & Sartor, D. (2024). *2024 United States Data Center Energy Usage Report* (LBNL-2001637). Ernest Orlando Lawrence Berkeley National Laboratory. https://eta-publications.lbl.gov/sites/default/files/2024-12/us_data_center_energy_usage_report_lbnl-2001637_0.pdf

[71] Assessment of the energy performance and sustainability of data centres in EU - First technical report https://op.europa.eu/en/publication-detail/-/publication/83be4c3e-5c79-11f0-a9d0-01aa75ed71a1/language-en

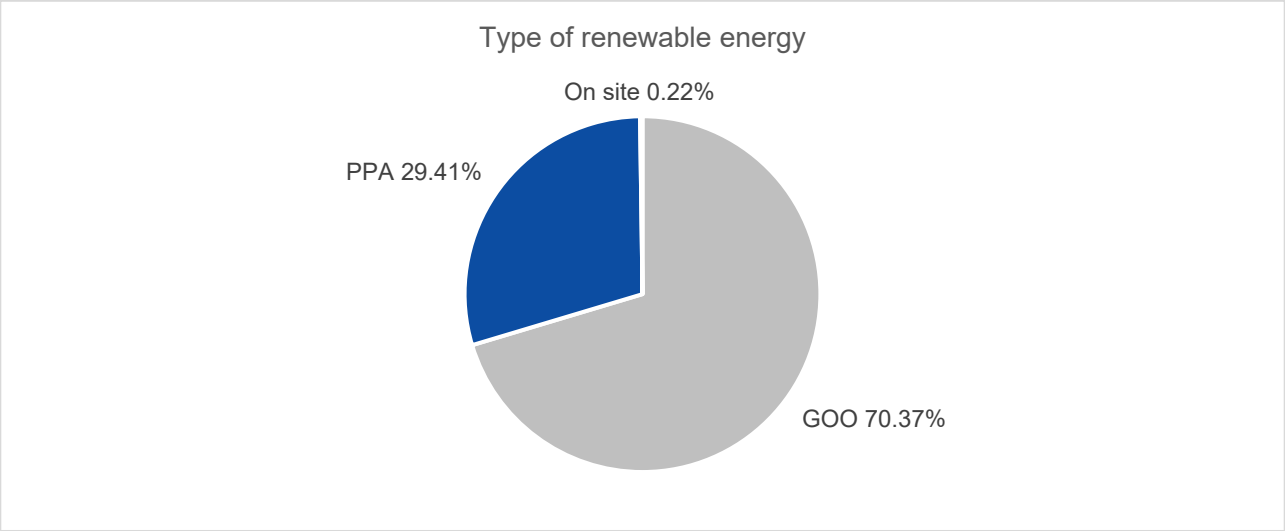
[72] Uptime Institute. (2025). *Executive Summary: Uptime Institute's Global Data Center Survey Results 2025*. https://uptimeinstitute.com/resources/research-and-reports/uptime-institute-global-data-center-survey-results-2025

[73] https://www.tu.berlin/en/news-from-tu-berlin/24-7-oekostrom-ansatz-treibt-innovationen-an

The current situation is that data centres in the EU already in 2023 purchased 86% of their energy from renewable sources, according to the reported data (see also71). With 70.4 %, the biggest share of renewable power is purchased through GoO (see also Figure 27). Around 29.4% is based on PPA, and only 0.22% are on-site generation.

Looking at this data, it seems feasible to aim for 100% renewable energy (EU wide REF=1.00) by 2030 in data centres. In the medium term (e.g. 2035-2037) however, decarbonising the power sector will require further goals to be set to strengthen the spatial and temporal connection between generation and consumption; for example, with more granular hourly certificates that are also based on new production facilities (additionality). The first data centre operators have already published commitments in this direction and are implementing projects.[74] The RED III[75] directive adjusted the current minimum size of a guarantee of origin to any fraction from a MWh, which still is a multiple of 1 Wh, and aims at much mor granular time correlation. Both developments in the RED are perfect fondations towards the more granular green power supply for data centres.

Figure 27 - Types of renewable energy sources in data centres in the EU 2023



GHG emissions of backup power systems

Other greenhouse gas emissions generated by the operation of data centres include emissions from backup power generators. Unlike CO_2-free power generation which can be fully implemented outside of a data centre, avoiding these emissions requires real changes in data centre infrastructure, which many operators already see as an obstacle.

Backup generators usually use Diesel (in some cases natural gas) and are activated only very rarely. According to the CEER-ECRB benchmarking report, in most EU countries, there are on average fewer than 10 unplanned interruptions per customer per year, and in many countries even fewer than one unplanned interruption.[76] These interruptions add up to just over 5 hours per year per customer. In countries with a strong data centre market, such as Germany and the Netherlands, interruptions are generally well below 50 minutes per customer per year on average. In such countries, the test runs of the backup generators to test their reliability make up the biggest share of backup power related emissions. It is also worth noting that backup generators (1-50 MW, <500 hr./a) are exempt

[74] https://www.theclimategroup.org/247

[75] DIRECTIVE (EU) 2023/2413 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652

[76] https://www.ceer.eu/wp-content/uploads/2024/04/7th-Benchmarking-Report-2022.pdf

from strict emission limit values (NOx, SO2, PM, etc.) in the Medium Combustion Plant Directive, which could be another reason to consider replacing them, especially in inhabited areas.

Due to the significance of the emissions from backup generators, the Net-Zero Innovation Hub for Data Centres launched a Request for Innovation in 2025[77], with the aim of adapting technical innovations in this area to the needs of data centres as quickly as possible and scaling them to GW power classes. On the one hand, this should help providers of such solutions to tailor their solutions to data centres and, at the same time, to get market access. For data centres, on the other hand, this offers the opportunity to obtain a proven, reliable and standardised solution.

Replacing diesel or natural gas-powered backup generators is not easy. Due to their high energy density/storable capacity and refill ability by tanker truck, a high level of operational continuity can be guaranteed in crisis situations, even beyond the typical 24/48-hour tank capacity. Options aside from traditional generators are:

- **Fuel cells** could be one of the alternatives currently being considered. A data centre operator in the US has been using fuel cells for this purpose for many years.[78] In the medium term, green hydrogen could be used as fuel, completely decarbonising the operation of such fuel cells. However, this requires further demonstration projects and a reliable supply infrastructure that can be maintained even in times of crisis.
- **Renewable liquid fuels, like HVO** could be used to make existing diesel backup generators more climate friendly. Operators also report regulatory difficulties (at least in Germany), as exemptions for the operation of backup generators are often tied to a specific fuel. A switch to HVO therefore requires a new permit; the use of diesel in the event of supply shortages in crisis situations should also be possible as an exception. Besides reducing GHG emissions because of a more circular carbon process and very reduced SO_2 values, the use of HVO still creates NO_x emissions.
- **Natural Gas with Renewable Gas / Biogas / e-Methane** does have less PM, SO_2 emissions compared to diesel engines and can be used instead of natural gas in the short to medium term, depending on the local supply situation.
- **Geo redundant data centre infrastructures** distributed over whole continents, or the globe keep not fully utilised so that in the case of an outage at one site, other locations will automatically take over their compute/storage tasks. In modern applications (cloud native) is common, that services are run on highly distributed compute and storage infrastructure and can be shifted to other locations. In the case of an outage, it could be useful to have minutes or hours for migrating stateful applications, but such time spans can be provided by purely battery-based UPS.

Fuel cells are already in operation with Equinix data centres, demonstrating the technical feasibility. Equinix usually uses solid oxide fuel cells, which can handle multiple fuels and at least one site is operated by biogas.[79] But using hydrogen (or green/renewable hydrogen) is usually possible with the same technology.

Existing diesel gensets can usually switch to HVO (hydrotreated vegetable oil) with no or minimal retrofit and there are couple of operators that have switched already to this fuel.[80,81,82,83] The

[77] https://www.netzerodatacenters.com/rfi-backup-solutions
[78] https://www.bloomenergy.com/news/bloom-energy-expands-data-center-power-agreement-with-equinix-surpassing-100mw/
[79] https://investor.equinix.com/news-events/press-releases/detail/452/equinix-to-install-bloom-energy-fuel-cells-at-silicon
[80] https://www.aboutamazon.eu/news/sustainability/harnessing-the-power-of-plants-to-decarbonise-our-data-centres
[81] https://datacentremagazine.com/articles/is-hvo-fuel-actually-taking-off-in-the-data-centre-industry
[82] https://www.mtu-solutions.com/na/en/stories/power-generation/diesel-generator-sets/wood-hvo-and-a-touch-of-swedish-romanticism-how-to-make-data-centers-sustainable.html
[83] https://www.inprord.com/en/hydrogenated-vegetable-oil-hvo-datacentres/

feasibility depends though more on the local supply structure for HVO and on the regulatory requirements for using existing gensets with HVO. The price for HVO is usually slightly higher than the price for Diesel; but at the low number of operational hours, the fuel price is usually not a significant factor for the total cost of ownership. The switch towards geo-redundancy instead of redundancy in the power supply is for many cloud-based services technically possible, but the required underutilisation and additional storage redundancy can be questioned in terms of overall system efficiency and could add large extra cost.

GHG emissions by refrigerants

Another source of greenhouse gas emissions in data centres are **leaking refrigerants**. Data centres require cooling to maintain a stable temperature for their servers. Traditionally, refrigerants are used in compressor cooling systems for this purpose. Many of these substances – such as HFCs (hydrofluorocarbons) – have a very high global warming potential (GWP), which in some cases is several thousand times higher than that of CO_2. Any leakage therefore causes considerable damage to the climate.

To reduce these emissions, there are some technical options:

- Install cooling systems that use low GWP refrigerants below 150. Some of these refrigerants can be unsuitable from the point of view of industry stakeholders due to their flammability. There are also refrigerants with which the cooling system achieves a poorer COP than with conventional refrigerants. This can have a negative impact on the energy efficiency or PUE of the data centre. DG CLIMA of the European Commission provides information on alternative refrigerants and their specifications.[84]
- Use of (indirect) free cooling in data centres combined with adiabatic cooling in regions where water is sustainably available and where temperatures are suitable.
- Use of (hot-) liquid cooling at temperature ranges which lay low enough to provide stable operation of computing equipment but also above outside temperatures all year. Various on-chip/immersion cooling technologies exist, that can operate in temperature ranges ~35-60°C. They can dissipate heat to the environment all year round. Such a cooling system would also work hand in hand with waste heat utilisation in the data centre.
- Use of natural sources (ground water, river water) that provide all year low enough temperatures for cooling or place a data centre in a region, where all year round the environment temperature is low enough.

These options are only possible for new (or fully retrofitted) data centres, as the interruption, which usually comes at a conversion of the cooling system, is not possible during operation. The EU F-Gas Regulation[85] already sets out clear guidelines for the phase-out of climate-damaging refrigerants. New data centres have much more leeway than existing data centres when it comes to implementing and adapting to this regulation. Nevertheless, due to the decreasing quantities of fluorinated refrigerants, even these will increasingly be forced to take action in the mid-term.

Embodied emissions of IT-equipment, the building and the data centre infrastructure

Producing semiconductors, metals, batteries, and enclosures involves high-temperature industrial processes, mining, and global transport. Especially the production of the most advanced semiconductors, based on extreme ultraviolet lithography process consumes enormous amounts of

[84] https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/climate-friendly-alternatives-f-gases_en

[85] REGULATION (EU) 2024/573 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014, https://eur-lex.europa.eu/eli/reg/2024/573/oj/eng

energy.[86] Also, the whole building, the server racks, the batteries and the UPS equipment come with large amounts of embodied CO_2. As mentioned earlier, there are hardly any reliable quantitative figures available on the extent of these embodied emissions.

Some options to reduce these emissions are:

- Longer hardware lifecycles and circular economy models (reuse, refurbishment, modular upgrades)
- Using low-carbon materials (e.g. low-carbon concrete & steel) for the building as well as for the infrastructure
- Using green and recycled metals for server racks and piping infrastructure
- Decarbonising the complex production processes of chips and other server hardware (mostly by carbon free energy in producing countries)

There are many ways to reduce these emissions, one of the easiest probably is to use longer hardware refresh cycles, which became increasingly popular in the last years.[87] Many of the current performance increases of servers are coming with strong increase of their power consumption – which makes a fast refresh cycle slightly less attractive.[88] For some purposes like AI and very dense computing tasks, specific new hardware may be required. Some players in the data centre industry have very active strategies to address and effectively reduce their Scope 3 emissions. However, many of these emissions are beyond the control of individual operators and occur outside the EU.

The areas shown, their share and the ease of reducing emissions are presented as overview in the table below:

Table 13 - Overview of emission sources

Type of emissions	Main Sources of GHG Emissions	Relative Share	Ease of Reduction	Reduction Strategies
Electricity use by IT and building technology (operation)	Electricity production for servers, storage, networking but also building infrastructure	Very High (currently in most regions, largest share)	Easier	Renewable energy procurement (PPAs, on-site solar/wind), energy-efficient operations of IT and building, long term 24/7 and onsite generation
Refrigerant leakage (operation)	Chillers, compressors, fans, refrigerant leakage (high GWP gases)	Medium	Moderate	Free cooling (air/water), especially when applied without refrigeration system (usually

[86] Trueman, C. (2024, October 7). *TSMC could account for 24% of Taiwan's electricity consumption by 2030*. https://www.datacenterdynamics.com/en/news/tsmc-could-account-for-24-of-taiwans-electricity-consumption-by-2030/

[87] Moss, S. (2023, February 3). *Google increases server life to six years, will save billions of dollars*. https://www.datacenterdynamics.com/en/news/google-increases-server-life-to-six-years-will-save-billions-of-dollars/

[88] Coroamă, V., Hinterholzer, S., Progni, K., & Dumbravă, O. (2025). *Energy Efficiency of Servers—Past and Possible Future Trends*. EDNA – IEA 4E TCP. https://www.borderstep.de/wp-content/uploads/2025/06/EDNA-EE-of-servers-FINAL.pdf

				liquid-based), low-GWP refrigerants
UPS test runs (operation)	Emissions of the diesel units for regular tests required for (e.g. Black-Building)	Medium	Medium-Hard	Alternative fuels (HVO [89], H2) and conversion fuel cells, large lithium batteries, location-based redundancy instead of diesel backup
IT equipment (embodied)	Chip fabrication is energy intensive; embodied emissions	High	Hard (supply chain is global, advanced semiconductors are energy-intensive)	Circular economy (reuse/refurbish), extend equipment lifetime, supplier decarbonisation
Building (embodied)	Cement, steel, aluminium and other building materials	Medium	Hard (materials are carbon-intensive and alternatives are limited)	Low-carbon concrete & steel, recycling materials
DC infrastructure and batteries (embodied)	Embodied carbon in server racks, cooling units, batteries	Medium	Hard (materials are carbon-intensive and alternatives are limited)	Low-carbon material production (e.g. steel and aluminium), reuse-/recycling materials, supplier engagement

Based on these considerations, it is possible to discuss which reduction targets can be considered feasible and for which other areas compensation mechanisms may be necessary to achieve a net-zero target:

Full decarbonisation of electricity consumption is feasible until 2030 with green PPA and GoO. In the mid- to long-term, further goals regarding more local and 24/7 and simultaneous generation are necessary to achieve actual system-wide decarbonisation in the electricity supply. In this regard, regulation should be more sensitive to small data centres, as some of them do not receive the best conditions for green PPAs. This puts them at a further competitive disadvantage, on top of the strong network effects and digital gravity already present in the digital sector.

For backup power supplies, CO_2-free alternative concepts will be feasible for all new data centres to be built by 2030. In many existing data centres, fuels should be converted to biological alternatives (HVO, biogas); in the medium term, this should also include renewable H2 and synfuels. In this case, it may make sense to allow offsetting of emissions via high-quality certificate for legacy data centres in 2030, as the conversion of the emergency power supply represents a very extensive disruption in data centre operations.

The GHG emissions from refrigeration systems, are also difficult to eliminate. The F-Gas regulation represents a good framework for reducing the climate impacts of refrigerants. Due to the limitation

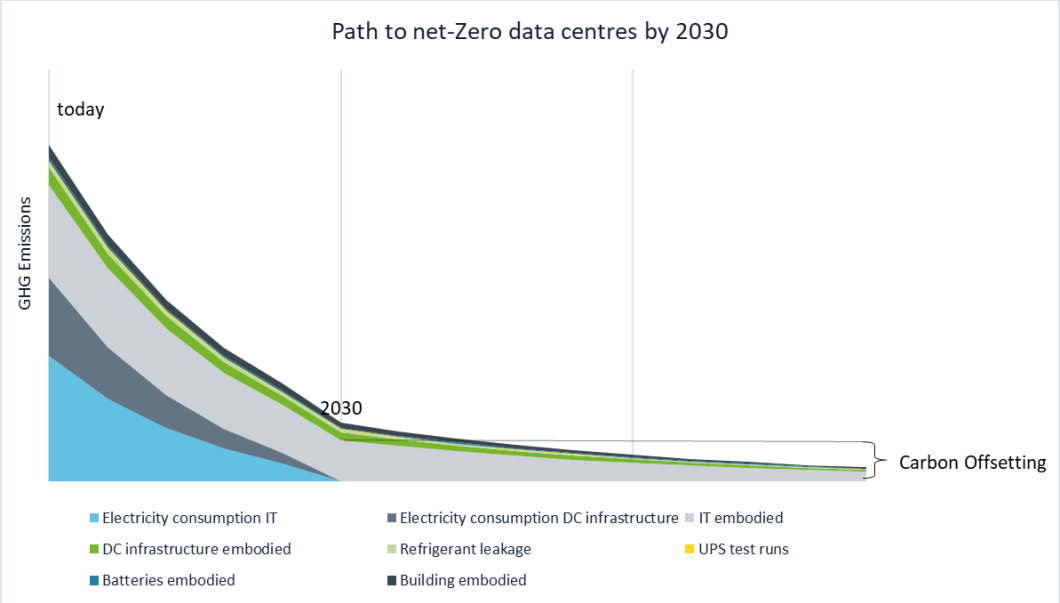
[89] HVO is an abbreviation of hydrated vegetable oil

of the total amounts, implementing stronger rules for data centres would probably just allow other sectors to consume/emit more. The EU has many innovative companies already providing new solutions in line with the F-Gas regulation. As it is very likely that there will be refrigerants in use especially by legacy data centres in 2030, here an offsetting will be necessary to achieve net-zero.

Regardless of this, it will be very difficult, if not impossible, to completely reduce upstream or embodied emissions by 2030. For new data centres, it should be a matter of course to carefully consider and weigh up the quantities/size and building materials for the building itself. Especially carbon-intense materials such as concrete and steel should either be reduced to a minimum or replaced with climate friendly alternatives. Where possible, existing empty buildings can also be refurbished for use as data centres. For example, there is currently a project under construction in Frankfurt[90,91]. Regarding the ICT equipment and its embodied emissions, labels like EPEAT and TCO could help to better understand the emissions and aims for reducing them. In this regard, it would be sensible to consider incorporating these factors more strongly into any future review of the label or minimum performance standards and to set incentives or thresholds about decarbonisation. However, complete decarbonisation of supply chains by 2030 does not appear to be technically or economically feasible under current conditions, which is why offsetting some of the remaining emissions with high-quality certificates should remain permitted in this area for the time being.

Based on the above emissions data and the prioritisation of the various segments, decarbonisation of the sector by 2030 could resemble the Figure 28 below. This is not an exact representation of the quantities involved, but is intended to illustrate the orders of magnitude.

Figure 28 - Qualitative representation of the reduction in greenhouse gas emissions in the data centre sector



The complete elimination of electricity-related emissions by 2030 will already reduce the sector's emissions relatively significantly. This also highlights the importance of embodied emissions, which is why efforts should increasingly be made to influence supply chains as well. With the implementation of the suggested minimum performance standards combined with increased competition towards sustainability due to the label, there is a high probability of achieving such a decarbonisation path.

[90] https://entwicklungsstadt.de/frankfurt-ostend-rechenzentrum-auf-historischem-neckermann-areal/
[91] https://www.fnp.de/frankfurt/die-ueberraschungen-des-neckermann-baus-93228807.html

4. Conclusions

During the study, very clear opportunities and ways to improve sustainability in the data centre sector have emerged. There has been a lot of controversial feedback in dialogue with the stakeholders, but still mostly constructive suggestions and a lot of positive feedback on the label and minimum performance standards which were developed.

The combination of minimum performance standards, which start at the lower end to gradually encourage the worst-performing data centres to modernise or to drive them out of the market, with the label is a particularly promising approach.

The in-detail analysis of best available technologies showed that that there are many ways to achieve good KPIs fulfilling the MPS, even retrospectively by means of modernisation. At the same time, the proposed label is another instrument that describes the sustainability of data centres and thus enables and fuels competition between the best operators. This softer (market-based) instrument does therefore primarily aim at other players whose data centres are already good but still have room for improvement.

a. The results in brief

Task 2.1 involved developing a rating scheme for sustainable data centres. By using the reported data, stakeholder interviews and workshops as well as online surveys, an extensive label was developed as proposed rating scheme.

The label evaluates data centres very comprehensively. Based on the efficient use of resources in the data centre, it looks at both the upstream effects (the origin of energy and water) and the downstream effects of waste heat utilisation and hardware circularity. It is based on established parameters, most of which are already available, which minimises the effort required to create this label.

Task 2.2 involved developing MPS that focus on efficiency and sustainability of data centres. This was based on existing EU-wide reporting data (Article 12 of the Directive (EU) 2023/1791 (the Energy Efficiency Directive) and the Commission Delegated Regulation (EU) 2024/1364), external benchmarks, and stakeholder input. The proposed MPS focus on three core KPIs: PUE, WUE, and REF. The thresholds are designed to be technically feasible and proportionate, and verifiable using the current reporting structure.

Specifically, the results suggest that:

- Existing data centres can achieve an operational PUE < 1.5 by 2030, while new data centres should target a design PUE < 1.3 and reach < 1.4 operationally within three years.
- A WUE < 0.4 m^3/MWh, set to be achieved by all data centres by 2030, is considered achievable across all climate zones when using net water input (Category 2).
- A REF of 100%, set to be achieved by all data centers by 2030, is already reached by over 70% of reported sites and is therefore seen as realistic and aligned with voluntary industry commitments.

The findings highlight that energy efficiency is strongly influenced by facility size, age and climate. Larger and newer data centres generally perform better, while older, small-scale facilities often require retrofitting to meet modern standards. Stakeholders emphasised the need for flexibility, especially for existing facilities, and supported differentiated targets that reflect climate and infrastructure conditions. The MPS thresholds were deliberately designed to minimise additional burden by relying solely on already reported data.

To support implementation, selected Best Available Techniques (BATs) were assessed across the representative data centre archetypes. They serve as examples of practical measures to help operators meet or exceed MPS thresholds under diverse conditions.

b. Summary of stakeholder feedback

Throughout the survey, workshops and interviews, stakeholders provided extensive feedback on the proposed MPS. While they welcomed the overall ambition, most participants voiced caution and emphasised the importance of proportionate, flexible measures and "better data" before introducing binding rules. The main points raised were:

- **Premature introduction:** Stakeholders argued that the first EED reporting cycle delivered incomplete and inconsistent data and, thus, it is too early to establish MPS. At least two full reporting cycles would be needed before reliable benchmarks can be established.
- **Fairness and feasibility:** PUE and WUE are heavily influenced by climate, water availability, and cooling technologies. Without climate normalisation, operators in warmer or water-stressed regions could be penalised despite making comparable efficiency efforts.
- **Smaller and legacy facilities:** These sites are particularly vulnerable, as they may lack the resources to meet uniform thresholds, which could lead to exclusion or market distortion.
- **Innovation and diversity risks:** Rigid MPS could hinder the adoption of new technologies, discourage investment, reduce regional diversity, and even exclude energy-efficient, yet water-intensive, cooling solutions.
- **Purpose:** The purpose of MPS was stressed by stakeholders as only to act as a regulatory floor to remove persistently inefficient sites. Drivers of ambition and innovation should remain rating schemes, voluntary initiatives, and incentive-based instruments.
- **Conditional support:** Some organisations supported the MPS in principle, provided it is phased-in gradually and that it is aligned with the EU rating scheme and designed to evolve over time. Several organisations suggested limiting the application to new facilities initially, while allowing existing facilities for flexibility and sufficient time to adapt.
- **Implementation measures:** Recommendations included third-party verification, stronger data quality controls, incentives for renewable energy procurement, better alignment with national regulations, and the use of existing voluntary commitments, such as the Climate Neutral Data Centre Pact, as references.

c. Recommendations for the improvement of the data reporting scheme within the Energy Efficiency Directive

The following adjustments are proposed for the existing reporting in connection to the work in this task:

1. The reported IT power should be the rated power (according to UPS, fuse protection, etc.) for all operators, as the 'installed' power was often incorrectly stated. Here the total power consumption of the IT was relatively often exactly 8 760 times the connected load (i.e. the power consumption was only divided by 365 and 24 to calculate the connected load). In some cases, the power consumption was even higher than this value, which would not be physically possible.
2. When reporting water consumption, standardised reporting according to WUE category 2 (according to EN50600-4-9) is recommended, as individual outliers that have reported extremely high values (but with category 1) are not meaningful. For the label as well as for

the MPS, this should be collected and presented as uniformly as possible to ensure comparability. Especially, water that is fed back to the source (not significantly chemically changed) should be considered as non-industrial use and be deducted from the inlet value, to have a more representative value for water depletion.

3. Besides GOO, PPA and on-site renewable electricity production, it should be transparent, which amount of renewable energy is produced at the same time (hourly) as the consumption happens.
4. The cooling degree days were very often reported incorrectly and outside the values expected within the respective Member States. To minimise errors in reporting, it is suggested that the database automatically retrieves the CDD from the Eurostat database based on the location (e.g. at NUTS3 level) and that these values do not have to be entered manually (or only if the operator explicitly requests this).
5. To achieve a better quality of the data, it would prove useful to implement an option to indicate that a data point was either not collected or can't be reported – to distinguish between actual zeros and unavailable data.
6. Stakeholders very often suggested that the threshold above which data centres must report should be set lower, as otherwise many small and inefficient data centres would be ignored. However, it is also clear that this would represent a proportionately higher effort for smaller operators, which is why setting this limit is more a political issue than a technical one. However, a reduction to 300 kW, as mandated in the German Energy Efficiency Act, would prove as a reasonable compromise. In any case, the European Commission could promote smaller data centres to voluntarily submit their data. There is also the possibility thatsignificantly more small data centres will voluntarily report their data in the coming years, in order to obtain a label that customers may also demand.

Annex 1 – Surveys/Interviews

Survey

Aim

The European Commission's Directorate for energy matters (DG ENER) has launched a tender for a new study in the domain of the energy efficiency and sustainability of data centres. This study's major goal is to **assess the energy-efficiency of data centres**, in line with the objectives of the Green Deal and the Digital Decade to have climate-neutral data centres, and to **propose potential additional measures such as the establishment of a common Union rating scheme vis-à-vis the sustainability of data centres.** This survey therefore consists of two types of questionaries: one for Task 1 and one for Task 2.

The survey focuses on specific indicators that data centres with an installed IT power demand of at least 500 kW will have to provide to the respective EU register in order to ensure compliance with Regulation (EU) 2024/136414.

As per the regulation, data centres need to report the following indicators:

Table 14 - Survey indicators

Energy and sustainability indicators	ICT capacity indicators	Data traffic indicators
• Installed IT power demand • Data centre total floor area • Data centre computer room floor area • Total energy consumption • Total energy consumption of IT equipment • Electrical grid function • Average battery capacity • Total water input • Total potable water input • Waste heat reused • Average waste heat temperature • Average setpoint IT equipment intake air temperature • Types of refrigerants • Cooling degree days • Total renewable energy consumption • Total renewable energy consumption from Guarantees of Origin	• ICT capacity for servers • ICT capacity for storage equipment	• Incoming traffic bandwidth • Outgoing traffic bandwidth • Incoming data traffic • Outgoing data traffic

• Total renewable energy consumption from Power Purchasing Agreements • Total renewable energy consumption from on-site renewables		

The objective of this survey is to contribute to the assessment of the completeness of the reported data from the first reporting period of 2024.

The survey on Task 2 will focus on comprehensive understanding of the practical challenges and industry readiness for potential adopting a new EU-wide rating scheme and establishment of MPS as stated in the Directive (EU) 2023/1791 Article 12(5).

The objective of this survey is to contribute to the development and implementation of effective measures that will **drive the data centre sector towards enhanced sustainability.**

The questionnaire for Task 1 will be split into two versions, one for data centre operators/owners and another for EU/national data centre associations and other types of stakeholders. The questionnaire for Task 2 will be common for all types of stakeholders, with the option to answer only question relevant for the respective stakeholder.

Task 2 questionaire: The need for, and feasibility of, an EU-wide rating scheme and minimum performance standards

General information (Page 1/3)

Which type of stakeholder group do you represent?

[ ] Data centre operators/owners

[ ] EU/National industry associations and initiatives

[ ] Others

_____

Which operator/organisation do you represent? (optional)

_____

In which Member State(s) is/are the data centre(s)/your organisation located? *Please select the Member State where the data centre you wish to provide feedback on is located. You can start another survey if you would like to provide responses for data centre(s) located in other Member States.*

Dropdown menu with all Member States + Others (please name the country)

_____

Common EU rating scheme for data centres (Page 2/3)

What benefits do you see in the implementation of a common EU sustainability rating scheme for data centres?

_____

What key sustainability indicators (e.g. energy efficiency, water usage, carbon footprint) should be included in such a scheme?

[ ] Power usage effectivenes (PUE / DCiE)

[ ] Energy reuse factor (ERF)

[ ] Renewable energy factor (REF)

[ ] Average emission factor (AEF)

[ ] Water usage effetiveness (WUE)

[ ] Carbon usage effectiveness (CUE)

[ ] Cooling capacity factor (CCF)

[ ] Data center power density (DCPD)

[ ] Other: _____

Minimum performance standards and transition towards net-zero emissions (Page 3/3)

Does your organisation have a developed internal sustainability plan?

[ ] Yes

[ ] No

(IF YES) What was your primary motivation to create and adapt the internal sustainability plan?

[ ] Economic reasons

[ ] Regulation / legislative

[ ] Demanded by customers

[ ] Other: _____

(IF Yes) What goals and/or performance standards have you stated in your internal sustainability plan?

_____

(IF Yes) In what timeframe do you expect to achieve your internal goals and/or performance standards?

[ ] < 1 year

[ ] 1 – 5 years

[ ] >5 years

Do you believe minimum performance standards should be mandated for data centres? Please, provide a brief argumentation.

_____

Do you believe the minimum requirements (regarding, e.g. heat reuse, energy efficiency, low-carbon energy) should be evaluated and mandated separately (e.g. the German “Energieeffizienzgesetz” states concrete requirements for PUE, ERF, REF) or in a combined metric/scheme?

[ ] Each minimum requirement should be reached separately per indicator

[ ] A common requirement should be defined by combining the indicators

Which aspects do you consider the most crucial in comparing different data centres?

[ ] Climate conditions

[ ] Local regulatory framework

[ ] Data centre size

[ ] Data centre type

[ ] Age of the data centre

[ ] Other: _____

How should minimum performance standards account for the abovementioned variations?

_____

What actions and/or approach would you consider suitable to improve the sustainability of existing data centres while also discouraging their premature decommissioning?

_____

Do you believe that the current EU sustainability goals are contradictory to the goals of the “digital decade”?

[ ] Yes

[ ] No

(IF Yes) What actions do you consider appropriate to mitigate the negative effects of the sustainability goals towards the EU digital decade targets? Please, provide a brief argumentation.

_____

AoB

Would you be interested in participating in an in-depth interview to discuss the points above? In case you are interested, our study team will contact you with further details.

( ) YES

( ) NO

(If Yes) Please provide us with an email address for further communication.

_____

Thank you for your contribution! For any questions or requests for further information, please do not hesitate to contact the study team at EUDCEAR@be.ey.com.

Interview

The European Commission’s DG ENER has launched a study to support the assessment of data centre energy efficiency and to propose additional measures in conjunction with refining the already established EU-wide rating scheme for the sustainability of data centres under Article 12 of the Energy Efficiency Directive (EED) Recast on data centres, and the Delegated Regulation (EU) 2024/1364 on the first phase of the establishment of a common Union rating scheme for data centres.

As per the regulation, data centres with an installed power demand of at least 500 kW are mandated to report the following indicators:

The objective of this interview is two-fold. First, the interview aims to contribute to the assessment of the completeness and quality of the reported data from the first reporting period by benchmarking

the figures from the reporting scheme with inputs from the industry and complementing the data whenever applicable. Second, the interview also aims to assess the energy efficiency and sustainability of data centres in Europe in the transition towards a sustainable data centre sector.

General information

1. Could you please introduce yourself and your role in your organisation?

Topic 2 - Next steps towards a sustainable data centres sector

2. What sustainability and energy-efficiency practices are currently in place at your data centre(s)?

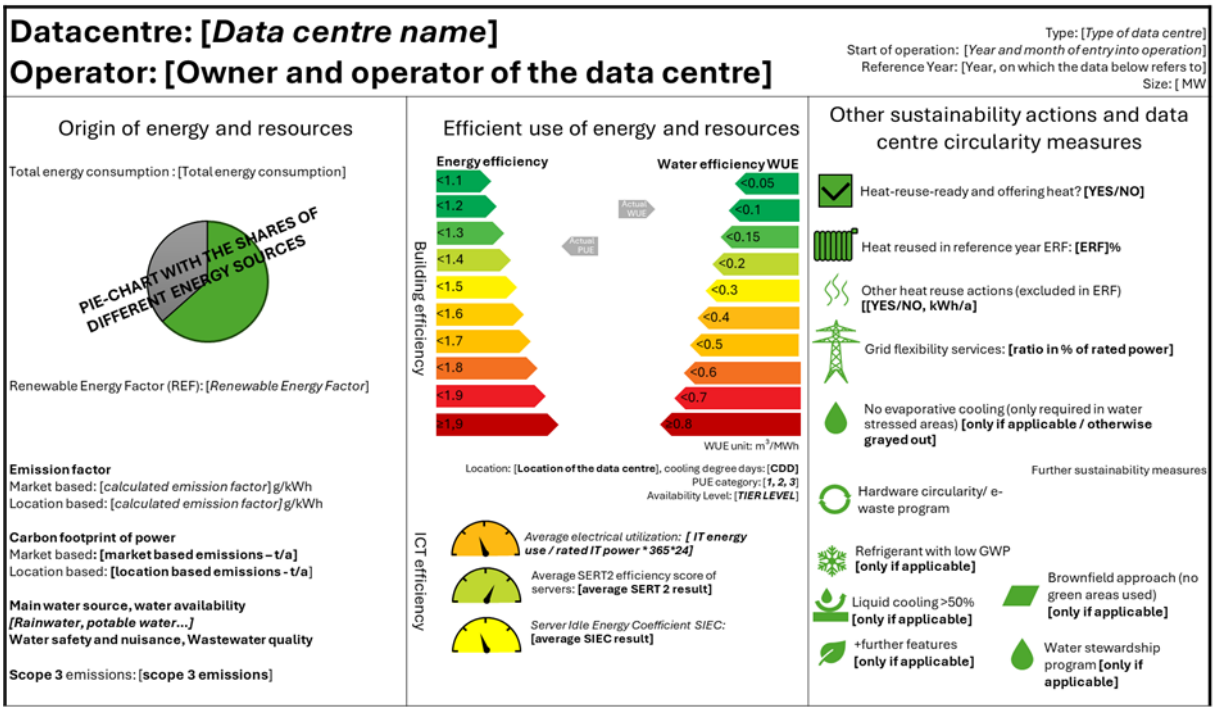
3. What are the key drivers behind sustainability initiatives related to data centres?

4. Are you aware of any challenges when implementing sustainable practices in data centres?

5. Where do you see the greatest opportunities for improving sustainability in the data centre industry?

6. In your opinion, which policies have been most effective in promoting sustainability in data centres?

7. Looking at the label (presenting the draft) for data centre sustainability in EU, do you think this is a good stating point to rate data centres regarding their sustainability? Is something missing?



8. Do you think it is feasible for data centres in the EU to be climate-neutral by 2030?

9. What are the “low hanging fruits” hereby and which emissions will be difficult to reduce/compensate for?

10. Do you believe that these “low hanging fruits” should be made mandatory in the form of minimum performance standards for a) new data centres, b) existing data centres?

11. Do you think that ambitious sustainability goals will have an impact on digitalisation in Europe (sovereignty, local economic power, digitalisation of the public sector, etc.)

Annex 2 – Detailed BAT rating

Table 15 - Detailed BAT rating

BATs	PUE	WUE	ERF	REF	Technical Maturity	Payback Time	organizational effort	Implementation time	(energy) savings potential	risk Impact	Comment	Total
Weights	20%	10%	10%	10%	10%	15%	5%	5%	10%	5%		
PUE												
Building measures												
Improve Building Insulation	3	0	0	0	5	3	3	3	3	5	Low-U-value insulation lowers chiller loads and cooling energy; proven but disruptive to retrofit, moderate payback.	2.40
Optimize Zoning / Layout	4	0	0	0	5	5	3	3	3	5	Cold/hot aisle separation improves airflow, reduces overcooling; quick and cost-effective, retrofit may be tricky.	2.90
High-Albedo Roof	2	0	0	0	5	3	4	3	2	5	Reflective roofs reduce heat gains and cooling demand; easy to implement during roof maintenance.	2.15
Check thermal envelope for Air tightness	3	0	0	0	5	5	5	5	2	5	Sealing thermal bridges minimizes warm air ingress; low-cost, fast, and effective for all buildings.	2.80
High Thermal Mass Materials in Construction	1	0	0	0	5	2	2	2	2	5	Stabilizes indoor temps, lowers peak loads; effective for new builds, not suited for retrofits.	1.65
Organizational measures												
Smart/AI-Driven Energy Management Systems	4	1	0	0	4	3	3	3	4	4	AI-driven cooling optimization reduces water and energy; requires skilled operation and monitoring.	2.65
Server Virtualization and Consolidation	3	0	0	0	5	5	4	5	4	5	Consolidating VMs cuts IT and cooling load, improves PUE; fast, mature solution with low risk.	2.95
Server Decommissioning Optimization	3	0	0	0	5	5	5	5	3	5	Removing ghost servers lowers IT and cooling demand; easy, low-investment, needs system access.	2.90
Data Hall Zoning for Targeted Cooling	4	0	0	0	5	4	5	5	4	5	Cooling zones adapted to thermal demand reduce energy waste; cheap, simple, may need small retrofit.	3.05
Electrical installation measures												
Variable Frequency Drives	4	0	0	0	5	3	4	3	5	5	Adjusts fan/pump/chiller power to real-time demand; lowers standby losses and boosts efficiency.	2.85

High-Efficiency Power Distribution Units	2	0	0	0	5	4	4	4	3	5	Use low-loss transformers, optimize voltage to cut distribution losses.	2.45
High Efficiency Uninterruptible Power Supply	3	0	0	0	5	4	4	4	4	4	UPS optimized for part-load reduces conversion losses and waste energy.	2.70
Heat-to-Power Conversion (e.g., Organic Rankine Cycle) / Peltier Elements	2	0	3	0	4	2	4	4	5	4	Uses waste heat for electricity; low efficiency, costly, but can reach PUE < 1 in some cases.	2.50
Switch to LEDs	1	0	0	0	5	5	5	5	3	5	Reduces lighting energy consumption significantly.	2.50
Motion sensors for light activation	1	0	0	0	5	5	5	5	2	5	Automatically turns off lights when unoccupied; reduces unnecessary energy use.	2.40
Cooling technology												
Cold-/Hot Aisle Containment	4	0	0	0	5	5	5	5	5	5	Prevents air mixing, lowers cooling demand through thermal separation.	3.30
High-Temperature Server Operation	4	0	2	0	4	5	4	4	4	3	Servers at 35°C+ cut cooling needs and allow better heat recovery; slight IT fan load increase.	3.10
Adiabatic Cooling Systems	2	-3	0	0	5	5	5	5	5	5	Lower water use, cuts cooling energy vs. evaporative systems; efficiency depends on replaced system.	2.60
Thermosyphon Cooling Systems	3	0	0	0	4	3	3	3	4	4	Passive system, low energy use, near 1.0 PUE if well-designed; higher maintenance.	2.35
Absorption Heat pump cooling	1	0	3	0	5	3	4	4	5	5	Uses >60°C waste heat for cooling; requires thermal input, may slightly worsen PUE but supports ERF.	2.60
Direct to chip cooling	4	0	2	0	4	4	5	4	4	5	Extracts high-temperature waste heat directly at the chip level, increasing thermal efficiency and ERF; ideal for advanced cooling systems like liquid cooling.	3.10
Immersion cooling	5	0	3	0	4	3	5	3	5	5	Fully submerges servers in dielectric fluid, eliminating most conventional cooling needs. Greatly improves PUE and ERF; ideal for high-density computing.	3.30
Geothermal or Aquifer-Based Cooling	3	0	0	0	5	3	3	3	4	4	Utilizes ground or aquifer temperature for passive cooling. Reduces cooling energy, but pump power and site suitability can affect benefits.	2.45
WUE												
Rainwater & Greywater Systems	0	3	0	0	5	2	4	4	1	5	Collects and treats water for cooling system make-up (e.g., adiabatic or evaporative cooling). Reduces freshwater use; treatment may be needed.	1.85
Integrated Water Management	0	2	0	0	5	5	2	5	4	5	Full monitoring and control over water inflow, reuse, and leakage. Reduces waste, supports optimization and sustainability reporting.	2.45
Free Cooling+ Filter	3	3	0	0	5	4	5	4	2	5	Uses ambient air with filtration instead of water-based cooling. Very low energy and water use; suitable for clean air regions.	2.90
Closed Loop Systems	0	4	0	0	5	5	5	4	5	5	Sealed circuits minimize evaporation and water loss; allows continuous reuse of water with little make-up needed.	2.85
Dry Adiabatic Cooling Systems	2	2	0	0	5	5	5	5	5	5	Air-cooled systems that spray water only during peak load. Significantly reduces water usage compared to wet cooling towers.	3.10
Condensate recovery systems	0	2	0	0	5	3	4	4	2	5	Captures condensate from AHUs/CRACs for reuse as make-up water, especially in humid climates. Cuts water demand effectively.	2.00
REF												
On-Site Energy generation												

On-Site PV	0	0	0	5	5	3	4	5	2	5	On-site solar power generation for direct use or grid feed-in. Proven, low PUE impact, but space-limited and weather-dependent.	2.35
On-Site Wind electricity generation	0	0	0	5	5	3	3	2	3	3	Generates renewable power on-site; technically mature, but faces challenges in zoning, spacing, and implementation.	2.15
On-site deep geothermal energy	0	0	0	5	4	1	1	1	4	3	Provides renewable electricity if >100 °C heat is available; otherwise, usable for shallow cooling. High CAPEX, location dependent.	1.70
On-site Fuel Cells	0	0	0	5	4	3	2	3	4	3	Provides on-site electricity from hydrogen or natural gas. Green hydrogen has high REF potential; maturity depends on supply.	2.15
Integrated Building-PV Facades (BIPV)	0	0	0	4	4	4	2	3	3	4	Solar elements integrated into façades or structures. Useful for new builds, less efficient than rooftop PV due to angle and exposure.	2.15
On-site Electrolysis and hydrogen storage	0	0	0	2	2	2	1	2	3	2	Produces and stores hydrogen on-site using surplus electricity. Valuable for flexibility, but not yet mature or broadly efficient.	1.25
Biogas & Waste-To-Energy CHP	0	0	3	3	5	3	2	1	3	2	Uses biogas/waste to produce electricity and heat (CHP). Mature, site-specific; can replace diesel backup and export surplus heat.	2.10
Energy Storage												
borehole heat exchangers	1	0	2	0	4	4	3	3	3	4	Store and extract heat from the ground for seasonal load balancing. Effective for ERF if winter heating is needed; site-specific.	2.20
Standard tank Storage	0	0	2	0	5	4	4	4	2	5	Simple hot water storage to shift thermal loads. Useful for peak shaving and energy reuse; no major energy savings alone.	2.15
Ice Storage + HP	2	0	2	0	4	3	3	3	3	4	Cold storage for shifting cooling demand to off-peak or renewable hours. Improves PUE slightly and enhances ERF.	2.25
Non-UPS Battery storage	0	0	0	3	5	3	3	4	2	4	Adds battery capacity beyond UPS for flexibility and renewable load shifting. Boosts REF, no direct effect on cooling but supports grid.	2.00
Sustainable Backup Power Systems	1	0	0	4	5	3	3	4	2	4	Replaces diesel gensets with batteries, fuel cells, and grid-interactive UPS. Improves resilience, REF, and slightly lowers PUE inefficiencies.	2.30
Organizational & Business Models												
PPAs	0	0	0	5	5	4	5	5	1	5	Financial tool to support renewable energy investments; does not reduce facility-side energy use, but enables green power sourcing.	2.45
Load-Oriented Scheduling (Energy-Aware Job Placement)	1	0	0	1	4	3	3	4	3	5	Shifts workloads to periods with lower carbon intensity or prices; aligns energy use with renewable supply (REF); effectiveness depends on workload flexibility.	2.05
ERF												
Heat recovery Sources												
Chilled water heat recovery	-2	0	1	0	5	5	5	5	2	5	Involves heat exchangers in chilled water loops; low-grade heat, typically needs a heat pump to upgrade for reuse.	1.90
Rear door heat exchangers direct waste heat use	-1	0	2	0	5	5	4	4	3	4	Uses higher return coolant temps for partial heat recovery; may still require a heat pump.	2.15
Waste Heat Recovery via Heat Pump	-1	0	3	0	5	4	4	5	3	5	Recovers cooling waste heat via heat pumps; adds electricity cost but enables moderate temperature reuse.	2.20
Direct to chip cooling direct waste heat use	0	0	3	0	4	4	3	4	4	3	Uses liquid cooling at the chip level; little need for central cooling; may require HP for reuse but has strong potential.	2.20
Immersion cooling direct waste heat use	0	0	5	0	4	3	2	3	5	5	Captures direct CPU/GPU waste heat through liquid immersion; suitable for medium-temperature reuse, HP may be needed.	2.35
Heat recovery Sinks												
High temperature sinks (>60°C)												

HT Waste heat to District Heating	0	0	4	0	5	1	5	5	5	2	Couples' data centre waste heat to local district heating systems; highly seasonal but with strong demand, already in use in some locations.	2.15
Industrial Process Heating	0	0	4	0	3	2	3	4	5	3	Waste heat can be reused in drying, preheating, or low-temperature industrial processes; high demand when present, application-specific.	2.00
Healthcare	0	0	5	0	4	3	4	5	4	4	Suitable for sterilization, space heating, etc.; ideal when close to large hospitals; demand is stable and moderate temperature.	2.40
Food industry	0	0	4	0	2	3	3	3	3	5	For brewing, pasteurization, sterilization; intermittent but promising; research ongoing to match temperature and timing.	1.90
Medium Temperature Sinks (40-60°C)												
Space heating office buildings	0	0	4	0	5	3	5	5	2	1	Seasonal reuse via direct exhaust air transfer from DCs to buildings; good for mixed-use urban areas.	2.10
Domestic Hot Water preparation	-1	0	4	0	5	3	3	4	4	5	Can support DHW needs with HPs; must meet Legionella protection temp; demand often lower than waste heat availability.	2.15
Low temperature District Heating	0	0	3	0	5	4	5	3	5	2	Applicable when heat pumps are not required; depends on network availability and temp levels.	2.40
MT Waste heat to Agri-tech	0	0	2	0	3	3	2	4	3	1	Waste heat used for grain drying, biomass processes; seasonal and batch-wise, but compatible with DC waste heat output.	1.60
MT Waste heat to food industry	0	0	4	0	2	4	3	4	3	5	Used in evaporation and dehydration (e.g. juices, dairy); mostly continuous, some batch processes may require short-term storage.	2.10
MT Waste heat to industry	0	0	3	0	3	3	3	3	5	3	Lowest-grade heat can still be used for boiler feedwater or preheating industrial fluids; demand varies by sector.	2.00
Thermal desalination	0	0	5	0	2	3	5	2	5	5	Multi-effect or membrane distillation powered by waste heat; ideal for coastal regions with freshwater scarcity; continuous operation possible.	2.25
Textile washing plants	0	0	4	0	1	4	2	4	3	4	Waste heat can support large-scale washing (e.g., doormats, textiles); implementation possible but intermittent, short-term storage may be required.	1.90
Low Temperature Sinks (25-40°C)												
Underfloor Heating	0	0	3	0	5	4	5	4	2	2	Direct heating via air/liquid heat exchanger; highly localized application, depends on specific building demand.	2.15
Preheating for HVAC System of office building	0	0	2	0	5	5	4	4	4	3	Uses waste heat to pre-warm incoming air in ventilation systems; lower demand unless applied in large office complexes.	2.40
Recharge Borehole HEX	1	0	3	0	4	4	5	3	3	2	Borehole systems used in winter heating must be recharged in summer; supports seasonal load shifting, especially peak shaving.	2.30
LT Waste heat to Agri-tech	0	0	3	0	3	5	5	5	4	4	Ideal for greenhouses, aquaculture, hydroponics, livestock or mushroom farming; temperature needs vary by application.	2.45
LT Waste heat to Algae Bioreactor	0	0	3	0	3	5	5	2	4	5	Uses low-temp waste heat to grow algae for sale or carbon capture; nearly continuous operation possible.	2.35
LT Waste heat to Swimming Pools	0	0	2	0	4	5	5	5	3	2	Seasonal but steady demand; very effective use of low-grade waste heat.	2.25
LT Waste heat to food industry	0	0	2	0	3	4	3	4	3	4	Supports preheating and processing of viscous liquids (e.g., pastes, dairy); intermittent loads, may need thermal storage.	1.95

Annex 3 – Archetypes

Table 16 - Data Centre Archetypes based on Median

Data centre type	kW	TOTAL ENERGY CONSUMPTION in kWh	TOTAL ENERGY IT EQUIP CONSUMPTION in kWh	Cooling in kWh	Power Supply (UPS etc.) in kWh	Ventilation in kWh	Lightning & Misc. In kWh	TOTAL WATER INPUT in m³	TOTAL RNW ENERGY CONSUMPTION in kWh	WASTE HEAT REUSED in kWh
New/High CDD/Large	12 819	50 513 127	41 235 397	2 319 432	4 059 007	2 319 432	579 858	52 585	50 513 127	-
New/High CDD/Medium	3 500	10 846 889	7 908 807	734 521	1 285 411	734 521	183 630	517	10 846 283	-
New/High CDD/Small	200	1 425 830	983 300	110 633	193 607	110 633	27 658	3 017	1 425 830	-
New/Low CDD/Large	81 500	302 413 729	273 992 718	7 105 253	12 434 192	7 105 253	1 776 313	143 256	302 413 729	58 946 256
New/Low CDD/Medium	2 450	10 613 312	9 374 321	309 748	542 059	309 748	77 437	50	10 605 864	-
New/Low CDD/Small	851	510	417	24	45	29	9	-	520	-
New/Medium CDD/Large	16 200	78 530 838	66 195 112	3 083 932	5 396 880	3 083 932	770 983	4 477	78 390 060	-
New/Medium CDD/Medium	3 300	10 427 685	7 900 650	631 759	1 105 578	631 759	157 940	295	10 427 685	-
New/Medium CDD/Small	630	2 605 782	1 685 347	230 109	402 690	230 109	57 527	-	905 299	-
Average/High CDD/Large	11 750	49 793 137	40 598 067	4 745 843	2 372 921	1 186 461	889 845	8 577	49 793 137	-
Average/High CDD/Medium	3 600	13 064 453	9 196 794	1 996 211	998 106	499 053	374 290	335	13 000 235	-
Average/High CDD/Small	721	6 620 515	4 180 909	1 259 151	629 576	314 788	236 091	327	218 061	-
Average/Low CDD/Large	180 000	953 837 298	869 311 749	43 626 090	21 813 045	10 906 522	8 179 892	410 089	953 837 298	-
Average/Low CDD/Medium	3 274	18 039 765	11 664 338	3 290 543	1 645 271	822 636	616 977	744	9 777 658	-
Average/Low CDD/Small	626	1 270 662	907 621	187 376	93 688	46 844	35 133	259	1 232 923	-
Average/Medium CDD/Large	15 025	79 431 706	59 553 003	10 259 976	5 129 988	2 564 994	1 923 745	46 713	78 849 796	-
Average/Medium CDD/Medium	2 000	10 547 944	8 799 850	902 242	451 121	225 561	169 170	266	9 751 918	-

Average/Medium CDD/Small	480	3 057 666	2 045 878	522 213	261 107	130 553	97 915	15	1 357 321	-
Old/High CDD/Large	16 400	71 466 443	53 312 285	9 077 079	3 630 832	4 356 998	1 089 249	4 000	71 190 943	-
Old/High CDD/Medium	1 990	17 940 348	11 472 549	3 233 899	1 293 560	1 552 272	388 068	680	14 405 548	-
Old/High CDD/Small	772	7 949 700	5 540 500	1 204 600	481 840	578 208	144 552	569	5 027 649	-
Old/Low CDD/Large	55 420	198 638 429	172 323 508	13 157 460	5 262 984	6 315 581	1 578 895	21 418	40 268 428	-
Old/Low CDD/Medium	1 600	13 220 244	8 221 885	2 499 180	999 672	1 199 606	299 902	177	13 220 244	-
Old/Low CDD/Small	700	8 501 846	4 500 000	2 000 923	800 369	960 443	240 111	138	5 275 000	-
Old/Medium CDD/Large	26 600	112 185 434	92 919 540	9 632 947	3 853 179	4 623 815	1 155 954	30 488	109 982 000	-
Old/Medium CDD/Medium	2 000	12 247 782	7 991 965	2 127 909	851 163	1 021 396	255 349	255	9 067 775	-
Old/Medium CDD/Small	539	4 053 691	2 408 971	822 360	328 944	394 733	98 683	4	2 680 032	-

Table 17 - Assumed existing Systems

Data centre type	Cooling System	IT Equipment	Power Supply	Ventilation	Lighting & Misc.
New/High CDD/Large	Rear Door Cooling or Direct Liquid/Immersion	High-density servers / blade	High-efficiency modular UPS	Efficient air handling or liquid assist	Smart LED + automation
New/High CDD/Medium	Rear Door or In-Row Cooling	High-density servers / blade	High-efficiency modular UPS	Efficient air handling or liquid assist	Smart LED + automation
New/High CDD/Small	CRAH (Efficient config)	High-density servers / blade	High-efficiency modular UPS	Efficient air handling or liquid assist	Smart LED + automation
New/Low CDD/Large	Rear Door Cooling or Direct Liquid/Immersion	High-density servers / blade	High-efficiency modular UPS	Efficient air handling or liquid assist	Smart LED + automation
New/Low CDD/Medium	Rear Door or In-Row Cooling	High-density servers / blade	High-efficiency modular UPS	Efficient air handling or liquid assist	Smart LED + automation
New/Low CDD/Small	CRAH (Efficient config)	High-density servers / blade	High-efficiency modular UPS	Efficient air handling or liquid assist	Smart LED + automation
New/Medium CDD/Large	Rear Door Cooling or Direct Liquid/Immersion	High-density servers / blade	High-efficiency modular UPS	Efficient air handling or liquid assist	Smart LED + automation
New/Medium CDD/Medium	Rear Door or In-Row Cooling	High-density servers / blade	High-efficiency modular UPS	Efficient air handling or liquid assist	Smart LED + automation
New/Medium CDD/Small	CRAH (Efficient config)	High-density servers / blade	High-efficiency modular UPS	Efficient air handling or liquid assist	Smart LED + automation
Average/High CDD/Large	CRAH or early In-Row	Rack servers with moderate density	Improved UPS (modular possible)	Ducted system with controls	LED with motion sensors
Average/High CDD/Medium	CRAH (Chilled water loop)	Rack servers with moderate density	Improved UPS (modular possible)	Ducted system with controls	LED with motion sensors
Average/High CDD/Small	CRAC or CRAH	Rack servers with moderate density	Improved UPS (modular possible)	Ducted system with controls	LED with motion sensors
Average/Low CDD/Large	CRAH or early In-Row	Rack servers with moderate density	Improved UPS (modular possible)	Ducted system with controls	LED with motion sensors

Average/Low CDD/Medium	CRAH (Chilled water loop)	Rack servers with moderate density	Improved UPS (modular possible)	Ducted system with controls	LED with motion sensors
Average/Low CDD/Small	CRAC or CRAH	Rack servers with moderate density	Improved UPS (modular possible)	Ducted system with controls	LED with motion sensors
Average/Medium CDD/Large	CRAH or early In-Row	Rack servers with moderate density	Improved UPS (modular possible)	Ducted system with controls	LED with motion sensors
Average/Medium CDD/Medium	CRAH (Chilled water loop)	Rack servers with moderate density	Improved UPS (modular possible)	Ducted system with controls	LED with motion sensors
Average/Medium CDD/Small	CRAC or CRAH	Rack servers with moderate density	Improved UPS (modular possible)	Ducted system with controls	LED with motion sensors
Old/High CDD/Large	CRAH with external chiller	Mixed servers (web, HPC, data)	Double-conversion UPS	Ducted variable-speed fans	Fluorescent or basic LED
Old/High CDD/Medium	CRAC or basic CRAH	Mixed servers (web, HPC, data)	Double-conversion UPS	Ducted variable-speed fans	Fluorescent or basic LED
Old/High CDD/Small	CRAC (Air-cooled)	Mixed servers (web, HPC, data)	Double-conversion UPS	Ducted variable-speed fans	Fluorescent or basic LED
Old/Low CDD/Large	CRAH with external chiller	Mixed servers (web, HPC, data)	Double-conversion UPS	Ducted variable-speed fans	Fluorescent or basic LED
Old/Low CDD/Medium	CRAC or basic CRAH	Mixed servers (web, HPC, data)	Double-conversion UPS	Ducted variable-speed fans	Fluorescent or basic LED
Old/Low CDD/Small	CRAC (Air-cooled)	Mixed servers (web, HPC, data)	Double-conversion UPS	Ducted variable-speed fans	Fluorescent or basic LED
Old/Medium CDD/Large	CRAH with external chiller	Mixed servers (web, HPC, data)	Double-conversion UPS	Ducted variable-speed fans	Fluorescent or basic LED
Old/Medium CDD/Medium	CRAC or basic CRAH	Mixed servers (web, HPC, data)	Double-conversion UPS	Ducted variable-speed fans	Fluorescent or basic LED
Old/Medium CDD/Small	CRAC (Air-cooled)	Mixed servers (web, HPC, data)	Double-conversion UPS	Ducted variable-speed fans	Fluorescent or basic LED

Annex 4 – External standards, policies and initiatives

Table 18 - External standards, policies and initiatives

Initiative/directive/report	Indicator:	PUE												WUE [m3/MWh]						REF										ERF										CER										CUE [kg/kWh]	Minimum CPU
	Deadline	2015	2019	2023	2024	2025	2026	2027	2029	2030	2031			2025	2027	2029	2030	2031	2040	2023	2024	2025	2026	2027	2029	2031			2023	2025	2026	2027	2028	2029	2031			2015	2019	2023	2024	2025	2027	2029	2031				
Green Public Procurement Guideline (UNEP: U4E)	Existin					1.5		1.4	1.3		1.2			1.5	1	0.5		0.2				50%		60%	70%	80%				30%		40%		50%	60%								2.5	2.9	3.8	5.7				
	Desig					1.4		1.3	1.2		1.1																																2.9	3.8	5.7	10				
	New					1.5		1.4	1.3		1.2																																2.5	2.9	3.8	5.7				
Guide to Environmental Sustainability Metrics (Schneider Electric)	Aim for	1.2-1.3[a-g]												0.30-0.45[g]						0.75-1[g]																															0-0.12	
Climate Neutral Data Centre Pact (EUDCA)	Existing DC									1.3-1.4						[f]			0.4			75%				100%				Explore possibilities																				
	Design					1.3-1.4[b]								[f]													100%																								
Directive GB 40879-2021 (China)	Mandat					1.15-																																											

Project DC-CFA (Singapore)	Aim					1.3[d]																																			
German Energy Efficiency Act (Germany)	Existi							1.5		1.3									50%			100%																			
	Design						1.2																				10%	15%	20%												
	New																										10%	15%	20%												
Noord-Holland initiative (Netherlands)	Design	1.16[e,g]																																							
Blauer Engel (Germany)	Req																	100							>0																20%
	Desig	1.6	1.5	1.3	1.25																											5	7	8	9						

[a] Achieved at 75-85% load
[b] Achieved at 100% load; hot-cold climate
[c] Inversely proportional to energy consumption
[d] Achieved at 100% load
[e] For DC over 5 MVA - ca. 4.25 MW
[f] DC should set their own target by defined date
[g] Deadline unknown

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