BUILDING ENERGY CODES
WORKING GROUP

EBC

Energy in Building and
Communities Programme

International review of energy efficiency in Data Centres for IEA EBC Building Energy Codes Working Group

March 2022

Technology Collaboration Programme
by iea

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Author

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The high priority research themes in the EBC Strategic Plan 2019–2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives: The strategic objectives of the EBC TCP are as follows:

– reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
– improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
– the creation of 'low tech', robust and affordable technologies;
– the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
– the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means: The strategic objectives of the EBC TCP will be achieved by the means listed below:

– the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
– benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
– improving smart control of building services technical installations, including occupant and operator interfaces;
– addressing data issues in buildings, including non-intrusive and secure data collection;
– the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019–2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)

Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting–Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
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Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
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Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings

Working Group–Energy Efficiency in Educational Buildings (*)
Working Group–Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group–Annex 36 Extension: The Energy Concept Adviser (*)
Working Group–HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group–Cities and Communities
Working Group–Building Energy Codes

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Very helpful inputs and critical reviews of the first version of the report were provided by Mark Acton, independent consultant; Clemente Allende, NABERS; Paul Bannister, DeltaQ Pty Ltd; Cate Berard, US Department of Energy; Paolo Bertoldi, Joint Research Council; Emi Bertoli, IEA; John Booth, Carbon3IT Ltd; John Clinger, ICF; Gareth Davies, London South Bank University; Sophia Flucker, Operational Intelligence; Ryan Fogle, US Environmental Protection Agency; Emma Fryer, techUK; Paolo Gemma, Huawei; Supratik Ghosh, NABERS; Dennis Grech, LCI Consultants; Steve Greenberg, LBNL; Nichole Hanus, LBNL; Adam Hinge, Sustainable Energy Partnerships; Ian Hoffman, LBNL; Walker Johnson, kW Engineering; George Kamiya, IEA; Christopher Payne, LBNL; Arman Shehabi, LBNL; Jeroen van Alphen, Ministry of Infrastructure and the Environment (Rijkswaterstaat), The Netherlands; Matt Wegner, London South Bank University; Stephen White, CSIRO; Anson Wu, Hansheng Ltd.

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I am grateful to all who provided their experience, insights, and time in the development of this report, though any errors are the responsibility of the author.

Fiona Brocklehurst, Ballarat Consulting

March 2022

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Executive Summary

Context

This report presents a review of international policies, standards and issues relating to energy efficiency in data centres for an international policy audience. This review suggests possible policy approaches to balance the economic and strategic benefits of data centres with managing their energy use and environmental impact.

The report is a contribution to the work of the Building Energy Codes Working Group (BECWG) under the International Energy Agency Energy in Buildings and Communities Technology Collaboration Programme (IEA EBC TCP). It is a revision of a report commissioned by the Australian Department of Industry, Science, Energy and Resources (DISER). The original report, completed in September 2021, was focused on Australian Government policy actions.

There has been substantial growth in the use of data centres in the last decade. Between 2010 and 2018, it was estimated that worldwide data centre capacity increased by 26 times, traffic instances increased by 11 times and compute instances increased by 6.5 times (Masanet et al. 2020). This trend is not expected to slow and may even increase.

Data centres are already notable consumers of energy and water. Thus, there is a substantial need to address the increased environmental impacts associated with emissions and water use in the future. It seems sensible therefore for governments to adopt policy measures to mitigate this impact.

There is scope for decoupling the growth in data centres from the consequent increase in energy demand. This international review found that there are the means to reduce energy use using existing technology and practices. It will take continuing attentiveness and action by governments and industry to achieve this.

Key findings

– Data centres have accomplished some efficiency gains, attributed to IT efficiency improvements and lower infrastructure energy use. Some of these gains are likely due to technology improvements, such as increased server efficiencies, and others from structural changes, including the shift to hyperscale data centres.

– Growth in edge computing (the use of data centres close to the point of use), which is required to support applications such as 5G, Artificial Intelligence and Virtual Reality, is likely to increase energy demand. This may be exacerbated by the fact that some of this development will be at the microscale and may therefore fall outside existing regulatory and permitting regimes and also may not be covered by current operational best practices.

– While most current focus is on energy use, impacts from water use may also become significant.

– Current regulations of energy efficiency by governments internationally are sparse and range from voluntary schemes, certification programs, additions to building codes, to minimum energy performance standards.

– Sustainable growth can be supported using existing technologies and management practices.

Possible pathways for action by governments

No single policy approach will address the sustainability impact of large and growing data centre use; the wide range of sizes, operational models and usage make it impossible for one policy to fit all. A range of statutory and voluntary approaches is needed. Examples of policies which have been adopted in different jurisdictions can provide a starting point for consideration by other governments. While any one policy could be effective, most policies will reinforce each other, meaning that the more policies that are adopted the greater impact each will have.

The policies suggested for consideration are summarised in the table below.

Table E1. Policies suggested for consideration

Policy	Source	Implementing measure	Benefit(s)
Mandatory disclosure of energy performance data centres operations	Pilot energy survey in the US, Federal US, proposed revision to the EU Energy Efficiency Directive	Set a statutory mandatory requirement to report (i.e. in confidence within government) or declare (put in the public domain) performance	– Attracting greater management attention, increasing the likelihood of organisations not already engaged on this topic to make improvements – Helping to identify the areas of highest impact and thereby to guide policy priorities – Enabling government to track progress and providing information for the monitoring and evaluation of any adopted policies – Driving competition between providers
Adopt Minimum Energy Performance Standards for servers and data storage	EU, Japan	Under existing legislative frameworks (eg in Australia the Greenhouse and Energy Minimum Standards Act).	– Greater IT efficiency that can have a multiplier effect and reduce infrastructure energy use proportionately.
Adopt Minimum Energy Performance Standards for data centres	China	Under existing legislative frameworks	– Providing a route to short term control of the energy use of new and refurbished data centres while more targeted metrics and measures are being developed
Extend coverage of an existing industry energy efficiency programme to data centres	The Netherlands	Under existing policies or initiatives	– Encouraging uptake of good practice – Providing data on data centre resource use
Set building code requirements for HVAC equipment or mechanical loads and electrical losses	California and Washington State, US	Revise building codes or consult with regional governments on whether they would consider following the precedent set by some US states using building codes to regulate energy performance of some data centre components.	– Reducing infrastructure energy use at the lowest cost (that is, at the design stage)
Provide good practice advice	Australia, EU, US, International	Update and expand existing advice produced for a national audience or provide signposts to existing advice.	– Enabling wider uptake of good practice.
Provide incentives for good practice	France, UK	Offer support, advice and financial incentives for good practice either through energy utility energy efficiency programmes or directly by governments.	– Encouraging the uptake of good practice.

Table E1 continued

Policy	Source	Implementing measure	Benefit(s)
Utilise public sector influence	EU, The Netherlands, New South Wales, US	Set best practice requirements for public sector operations and the services they procure	– Reducing environmental impact – Incentivising suppliers to improve their performance – Providing an exemplar for the private sector.
Develop or adopt, and promote a voluntary good practice certification/label for data centres	Australia, US	Adapt an existing national certificate/label, develop a new one or encourage adoption of an international one	– Enabling and encouraging the adoption of best practice

Further work

There are topics of interest which could be valuable in the development of effective policy, in order to identify and start to address additional environmental risks.

At a national level gathering **information on current data centre performance** through an industry wide survey of data centre energy use would give an indication of how data centres performance compares with published data for other jurisdictions and provide a baseline for future changes based on empirical evidence.

Others topics for investigation would benefit from international collaboration. Acting in concert with other governments would increase effectiveness, including:

1 **Engage with industry on effective metrics.** Industry and regulators lack a set of robust indicators for the performance of data centres to address this barrier to effective regulatory and voluntary action. Some work is underway on this internationally and in the EU; wider engagement would accelerate progress and increase the impact of this work.

2 **Undertake research on data centre use of potable water and ways to reduce it.** This is an understudied area; research is needed to identify best practice and possible policy options to encourage this.

3 **Undertake research on challenges from edge computing and how to address them.** It is not clear how regulations and best practices developed for 'conventional' data centres can be adapted to effectively cover the edge. Addressing this could become a high priority if some of the bullish growth projections for edge computing prove accurate.

Glossary of Terms

Term	Definition
AHU	Air Handling Unit
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
ANSI	The American National Standards Institute
BECWG	Building Energy Codes Working Group of the International Energy Agency Energy in Buildings and Communities Technology Collaboration Programme
BICSI	Building Industry Consulting Service International
CCA	Climate Change Agreements (UK)
CDN	Content Delivery Network–a geographically distributed group of servers which work together to provide fast delivery of Internet content.
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
Colo	Co-location data centre. Company which offers space to multiple customers in which to locate their own network(s), servers and storage equipment
COP	Coefficient Of Performance
DOI	Digital Object Identifier. A persistent identifier or handle used to identify objects uniquely, standardized by the International Organization for Standardization.
E3 Program	Equipment Energy Efficiency (E3) program (Australia)
EER	Energy Efficiency Ratio
EN	European Standards (documents that have been ratified by one of the 3 European Standards Organizations, CEN, CENELEC or ETSI)
EPBD	Energy Performance of Buildings Directive (EU)
ETSI	European Telecommunications Standards Institute
GDP	Gross Domestic Product
GPP	Green Public Procurement
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communications Technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
ITU	International Telecommunication Union
Latency	The time taken by a unit of data (typically a frame or packet) to travel from its originating device to its intended destination. Typically measured in milliseconds, latency represents the network delay that data will incur at single or repeated points in time between two or more endpoints.
MEPS	Minimum Energy Performance Standard
NABERS	National Australian Built Environment Rating System
POPs	Points of Presence -distributed data processing and storage resources
PUE	Power Usage Effectiveness: PUE = EDC/EIT ; where: EIT is the IT equipment energy consumption (annual) in kWh and includes: IT equipment and supplemental equipment; EDC is the total DC energy consumption (annual) in kWh and includes: EIT, power delivery, cooling system and others
SERT	Server Efficiency Rating Tool
SLA	Service Level Agreement
SNIA	Storage Networking Industry Association: a non-profit organization made up of member companies spanning information technology
UPS	Uninterruptible power system or supply

Background, objectives and methodology

This report presents a review of international policies, standards and issues relating to energy efficiency in data centres for an international policy audience. The report is a contribution to the work of the Building Energy Codes Working Group (BECWG) under the International Energy Agency Energy in Buildings and Communities Technology Collaboration Programme (IEA EBC TCP). It is the revision of a report for the Australian Department of Industry, Science, Energy and Resources (DISER) which was focused on Australian Government policy actions and which was completed in September 2021.

Background

Data centres have attracted significant investment in recent years with increasing dependence on cloud storage and increased loads on digital infrastructure as populations decentralise. This has increased demand for 'compute and store' or the ability to remotely work on, transform and store data on the internet. The international data centre market size is expected to grow significantly over the next five years (see Projections of market size and energy usage for details). As the world becomes increasingly reliant on the internet and mobile usage, data are increasingly seen less as a measure of information and more as an essential service and public utility. It is reasonably expected that the energy and emissions footprint of data centres will be increasingly important into the future. Accordingly, BECWG identified data centres as an important topic for future energy use and emissions reduction.

Outline and methodology

Organisation of this review

- **Chapter 1. Introduction to data centres** defines the various types of data centres and their key environmental impacts.
- **Chapter 2. Standards and Metrics** reviews the existing ecosystem of measuring energy efficiency with regard to data centre usage.
- **Chapter 3. Practices and trends in data centres** describes existing and emerging ownership models, and trends in energy efficiency.
- **Chapter 4. Regulations, performance standards and certificates** reviews international statutory and voluntary schemes.
- **Summary and recommendations** gives recommendations for policy options, identifies further areas of research and presents the conclusions.

Sources of Data

Data on the metrics and measurement standards used for data centres has been gathered from:

- Standards organisations (CEN/CENELEC/ETSI, 2020, ASHRAE 2016)
- Trade associations (for example techUK, Fryer and Gilmore 2017, or Afcom, Shapiro 2019)
- pages of web sites of companies offering support services to data centre operators (for example Acton 2019, Uptime Institute 2021)
- grey literature (for example Raje et al 2015)
- papers from academic journals (white literature, for example Reddy et al 2017)

No single source proved definitive, which is perhaps unsurprising given the multiplicity of standards and metrics, the different aspects covered and the fast rate of their development.

The initial data on the regulations, performance standards and certification schemes for data centres were the author's own experience from being part of the project team developing the EU's Green Public Procurement (GPP) Guidelines (European Commission, 2020). This included a review of existing regulations and certification schemes to see what could be learned from them in terms of which criteria were most relevant and where performance levels had been set (Dodd et al, 2020). This list was expanded using internet searches both generic and focused on particular countries of interest, such as China, Europe, Japan, Singapore and the USA. These were selected as being areas which were known to be hubs for data centres.

Wherever possible information on a scheme has been gathered from primary documents, that is, those authored or issued by the organisation which initiated or managed the scheme, which describe it in full. Sometimes this level of information was only available to members of a certification scheme; in these cases data were gathered from publicly available information – from the scheme itself, as reported in the literature or on a web site.

Across all topics of research information was gathered from:

- the Association for Computing Machinery (ACM) digital library
- the LBNL Center of Expertise for Energy Efficiency in Data Centers
- the Data Centre Alliance
- keyword searches using internet search engines.

The initial literature search took place from February to June 2021. A search for new policy developments was undertaken in December 2021.

Expert review

A draft of the first version of this report was provided to over 30 experts with experience in data centre technology and/or policy. Most of these responded and where possible their suggestions have been incorporated into the report. This process took place in July 2021. The respondents are listed in the Acknowledgements.

1. Introduction to data centres

This chapter defines a data centre, introduces the various types of data centres and their components and describes their key environmental impacts.

1.1 Definition and classifications of data centres

A data centre is a structure, or group of structures, dedicated to the centralised accommodation, interconnection and operation of information technology and network telecommunications equipment. Data centres provide data storage, processing and transport services with the associated facilities and infrastructures for power distribution and environmental control. This must be achieved with the necessary levels of resilience and security to provide the desired service availability.

Data centres can be classified as different types, as described in Table 1 Data centre product group type. (Dodd et al 2020).

Server rooms are small scale enterprise data centres[1] (that is, owned and operated by the company that owns the data), usually housed in an area of less than $50m^2$ and consisting of approximately 25 racks or less. Server rooms, also referred to as computer rooms or server closets, are rooms or parts of a building serving a specific IT load, determined by the power density of the equipment in the room. Server rooms may have some dedicated power and cooling capabilities or may use the HVAC facilities of the building they are located in.

Some data centres provide digital services in the cloud, where the customer pays for a service and the vendor provides and manages the ICT hardware/software and data centre equipment required to deliver the service. This includes the co-hosting of multiple customers, which may take the form of a cloud application environment. Different business models are associated with cloud services. It is noted that the scope of this report only extends to the data centre component.

The most common cloud services identified are as follows (Dodd et al 2020):

– **Infrastructure as a service (IaaS):** a service provider offers clients pay-as-you-go access to storage, networking, servers and other computing resources in the cloud.

– **Platform as a service (PaaS):** a service provider offers access to a cloud-based environment in which users can build and deliver applications. The provider supplies underlying infrastructure.

– **Software as a service (SaaS):** a service provider delivers software and applications through the internet. Users subscribe to the software and access it via the web or vendor Application Programme Interfaces.

1.2 Data centre components

An overview of data centre components is shown in Figure 1. And an overview of how these systems interrelate is shown in Figure 2, also from Schödwell et al (2013).

1 Enterprise data centres can also be large. For example banks may own and operate large data centres.

Table 1. Data centre product group type

Product group type	Definition
Enterprise data centre	A data centre which has the sole purpose of the delivery and management of services to its employees and customers and that is operated by an enterprise
Co-location data centre	A data centre facility in which multiple customers locate their own network(s), servers and storage equipment. Physical management of the equipment may be by the owner, a third party or the colo.
Managed Service Providers (MSP) data centre	A data centre offering server and data storage services where the customer pays for a service and the vendor provides and manages the required ICT hardware/ software and data centre equipment. This management service includes the co-hosting of multiple customers, which may take the form of a cloud application environment.

Figure 1. Data centre Components – from Schödwell et al 2013

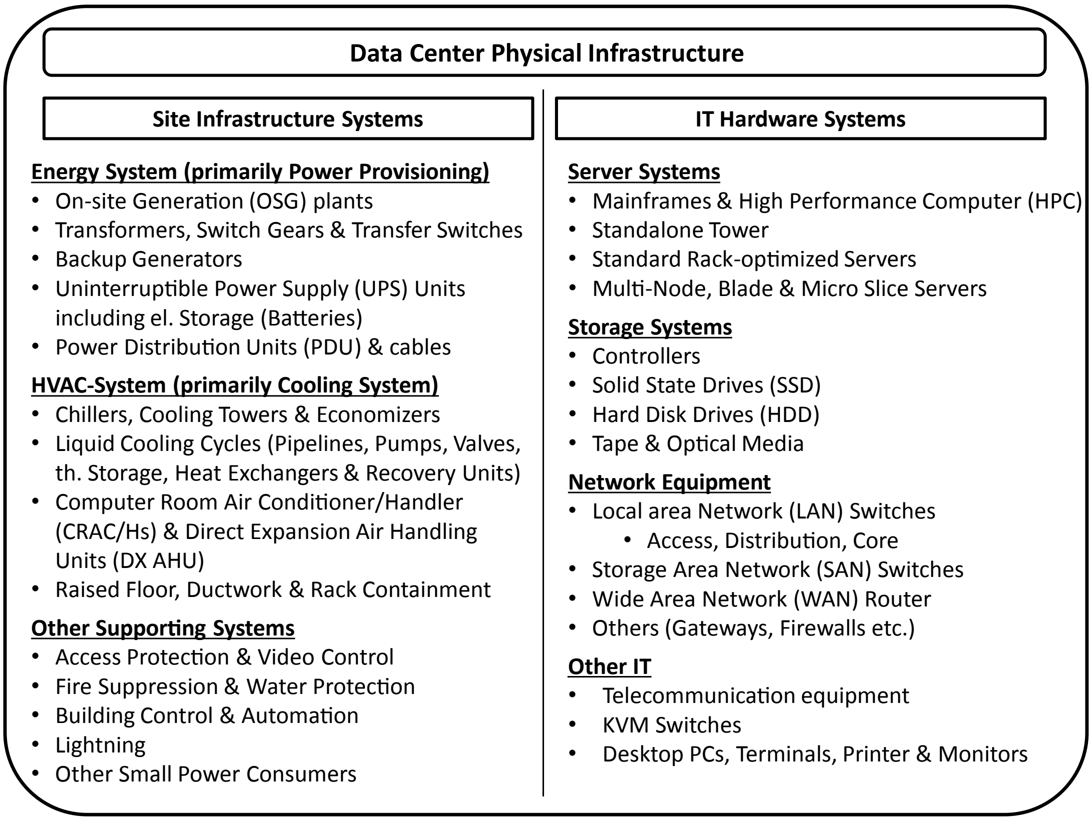
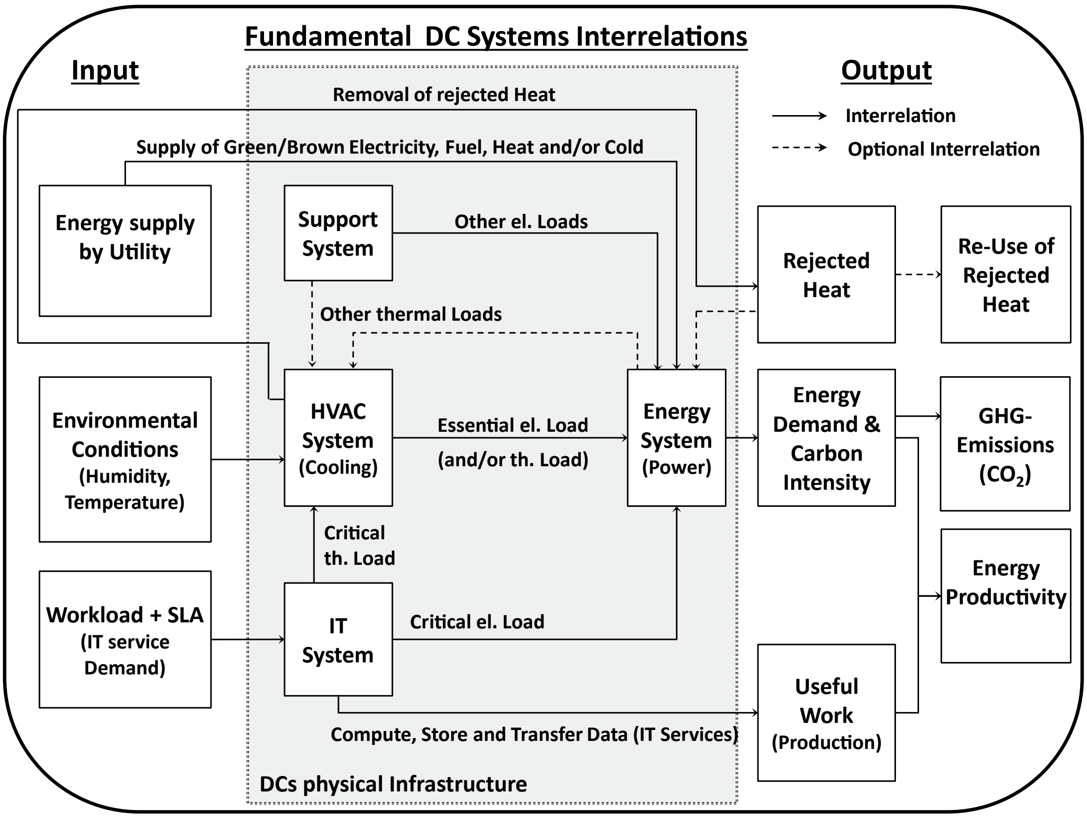


Figure 2. Interrelations of data centre function systems – from Schödwell et al 2013



1.3 Some key environmental impacts of data centres

Some areas for environmental improvement with high priority rankings and associated improvement strategies are shown in Table 2 (from Dodd et al, 2020). This list is not comprehensive; these and some other examples are considered in Chapter 3. Practices and trends in data centres.

Beyond this, researchers have considered the environmental impact over the whole life cycle, rather than just the in-use phase, Flucker et al (2018) for example, taking into account the embodied impact of IT equipment when considering replacing IT equipment with newer, more efficient kit.

The relationship between data centre reliability and environmental impacts

High reliability is the key requirement of most data centres. Many services delivered by data centres are intrinsically mission critical – for example enabling financial trading. Lawrence (2021) highlights systems that were not necessarily designed to be mission critical have become increasingly important as dependency on them has increased over time. Immediate access to data or an application has moved from a luxury to a necessity.

Lawrence (2021) states, based on industry wide survey results and other data, that the impact of outages can be significant. Apart from the financial impact, which can be substantial, impacts range from inconvenience and frustration to compliance breaches, reputational damage, and even loss of life.

Table 2. Data centre environmental hotspots and improvement strategies

Environmental hotspot	Improvement strategy	Application level (i.e. focus area)
Energy mix to supply electricity	Procurement of on-site/near-site electricity	Whole data centre
Energy mix to supply electricity	Hosting/location of server and data storage services in data centre with high renewable electricity share	Whole data centre
Energy consumption in the use phase	Ensure a high rate of utilisation of IT equipment	IT system
Energy consumption in the use phase	Select highly energy efficient server(s)	IT system
Energy consumption in the use phase	Select ICT equipment operating at higher temperature	IT system
Energy consumption in the use phase	Ensure continuous monitoring of the energy consumption of the IT and mechanical and electrical components of the data centre	Whole data centre
Energy consumption in the use phase	Hosting/location of server and data storage services in data centre with low Power Usage Effectiveness (PUE)	M&E systems
Energy consumption in the use phase	Implement Cooling System Best Practices	M&E systems
Energy consumption in the use phase	Reduce energy consumption for cooling systems (operating more hours in free cooling conditions)	M&E systems
Energy consumption in the use phase	Minimise waste heat by reuse in a district heating	M&E systems
Trade-off energy efficiency and extended lifetime	Find optimal refresh rate	IT system
Right-sizing of data centre capacity, availability and redundancy	Increase IT utilisation	IT system
Right-sizing of data centre capacity, availability and redundancy	Consolidation of IT equipment	IT system

Source: Dodd et al (2020)

It is clear that measures to improve data centre sustainability must not compromise reliability.

Dodd et al (2020) report that there can be a perception that sustainability and reliability are mutually exclusive. This is not the case, but it is important to demonstrate that measures to improve environmental performance do not necessarily increase risk and in some cases may reduce it.[2] Concerns relating to reliability may hamper efforts to implement best practices, e.g. through resistance to changing legacy practices and designs. In order to address this, when making changes, reliability must be considered both at a component and system level.

Dodd et al (2020) gave an example of how reliability tends to overshadow environmental concerns:

To achieve high reliability levels, redundant components and systems are installed. Where two systems are installed for redundancy, each system may only be loaded to 50% maximum so that in a failure event the alternative system is not overloaded. Designers and operators often build additional margins into this, resulting in low loads during normal operation. This is compounded by partial loads – most facilities never reach 100% design load and operate for years at 50% load or lower. Also, ICT equipment is often installed with overprovisioned capacity. Extra capacity means additional embodied impact and equipment operating at low loads is usually not at its most efficient condition.

2 For example switching to backup power that does not rely on fossil fuels can increase sustainability and increase resilience.

2. Standards and metrics

Accurate and robust standards and metrics are necessary to support comparability of the functioning of data centres and regulate environmental performance. An assortment of standards and metrics have evolved around data centres, which are referred to throughout the report. These are outlined in this section and described in more detail in Appendix 1. Standards listing and Appendix 8. Descriptions of regulations, certification and other initiatives.

2.1 Standards

The main providers of standards for data centres are CEN, CENELEC or ETSI in Europe, (EN standards), ASHRAE, ANSI and BICSI in the USA and IEC/ISO internationally.

In many areas standards have been strongly industry led, where metrics developed by industry are then adopted and formalised as standards. One example of this is the Green Grid,[1] which developed several metrics including Power Usage Effectiveness (PUE) and Water Usage Effectiveness (WUE), (Patterson et al, 2011). These metrics have since been novated into EN and ISO standards. The Green Grid *Data Centre Maturity Model* is currently in preparation as EN 5060051, Data Centre Maturity Model. Another example is the long-standing EU Code of Conduct on Data Centre Energy Efficiency, whose best practice guidelines (Acton et al 2021), funded by the EU, have largely been adopted into an EN best practice standards report TR5060099-1, *Data centre facilities and infrastructures – Recommended practices for energy management*.

A complete listing of standards which were identified as relating to data centre energy and environmental regulation is given in Appendix 1. Standards listing.

This listing is grouped into four applications:

1 Security, availability and resilience

2 Key performance indicators and data centre operation

3 Data Centre Components (servers, HVAC, power supplies, cabling)

4 Environmental management and audits (non-specific)

This report focuses on the test standards which relate to the regulations, performance standards and certifications discussed in that section.

Standards Related to security, availability and resilience

CEN/CENELEC provide a set of measurement standards which offer both overall and more specific guidance on security, availability and resilience of specific systems. These systems include:

- building construction
- power supply and distribution
- environmental control
- telecommunications cabling infrastructure
- security systems
- earthquake risk
- impact analysis and management and operation.

ISO/IEC provide a similar set of guidance (earthquake risk is in preparation) which are reported as being identical. ANSI/BICSI provide a US standard on design and implementation best practice which is understood to have similar coverage. All these standards are listed in Appendix 1. Standards listing.

This set of standards is important for energy and sustainability consideration as they inform the construction and operation of data centres, in order to support the required availability.

Key performance indicators and best practice

CEN/CENELEC provide a set of measurement standards which offer overall guidance on performance measurement and for a set of Key Performance Indicators (KPIs) on energy use, water use and so on.

As for standards related to security, availability and resilience (above) ISO/IEC provide a similar set of standards to those of CEN/CENELEC for KPIs (earthquake risk is in preparation) which are reported as being identical. ANSI/BICSI provide a US standard on design and

1 The Green Grid is an affiliate membership level of the Information Technology Industry Council (ITI), a trade association for the tech sector.

implementation best practice which is understood to have similar coverage. All of these standards are listed in Appendix 1. Standards listing.

Many of the KPIs are metrics, discussed in Metrics and used in one or other of the performance standards and certification described in Chapter 4. Regulations, performance standards and certifications.

Standards related to data centre components

Standards relating to data centre components can be grouped into two categories: temperature and humidity tolerances, and servers.

Temperature and humidity tolerances

Demand for power and cooling of a data centre is created by the IT equipment. Selecting ICT hardware which is able to operate at higher temperatures can result in a reduction in the energy requirements for refrigeration and more free cooling hours.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has produced guidelines on temperature and humidity allowances for air-cooled equipment.[2] The allowable ranges for both temperature and humidity fall under four ASHRAE classes: A1 to A4 (described in ASHRAE 2016). They are part of the thermal guidance provided by ASHRAE Technical Committee (TC) 9.9, most recently updated in 2021 (Fifth edition). The tightest tolerances apply to class A1 and the most relaxed to A4.

These classifications appear to be widely applied when specifying the operating environment for IT equipment in data centres. For example, in the EU ecodesign (MEPS) server regulation (European Union 2019) IT manufacturers are required to declare the environmental class of their product according to the ASHRAE TC 9.9 Environmental Classes for IT equipment.

ASHRAE have also introduced guidance for liquid cooling, with classes: W1 to W5. W1 has the tightest tolerances and W5 the most relaxed. For more detail see Dodd et al (2020).

ETSI EN 300 019-1- *Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment*, also defines classes for operating temperature and humidity.

Servers

The test standards for server energy efficiency are:

- ISO/IEC 30134-4 *Information technology — Data centres — Key performance indicators — Part 4: IT Equipment Energy Efficiency for servers* (which is referenced by EN50600 *Data centre facilities and infrastructures* and ISO/IEC 22237 *Data Center Facilities and Infrastructures*)
- ETSI–EN 303 470.

There is also ISO/IEC 21836, *Information technology — Data centres — Server energy effectiveness metric*, which

2 The official title is “Thermal Guidelines for Data Processing Environments”

specifies a measurement method to assess and report the energy effectiveness of a computer server.

These, together with standards for data storage and power supplies are listed in Appendix 1. Standards listing.

There are also tools which serve the function of test standards which are described alongside the regulations and labels they support in Appendix 8. Descriptions of regulations, certification and other initiatives.

Environmental management and audits
Some data centre certifications and agreements refer to more general standards for managing environmental performance, energy management or energy audits. These are:

- EN 16247, Energy audits
- ISO 14001, Environmental Management
- ISO 50001, Energy management

2.2 Metrics

One of the difficulties in identifying a single metric for data centre energy efficiency, the wide range of uses, is described in some text from techUK Data Centres Technical Committee (2017):

> Why not use Bits per Watt as a data centre KPI?
>
> Data centres do different jobs. A single metric would favour some operations and penalise others. For example, high performance computing (HPC) involves very high quantities of data processing, very high utilisation of servers, high energy intensity (e.g. 30kW per cabinet) and high value but low volume output. Weather maps for instance use HPC because the size and complexity of the models and the sheer volume of data. However, the product is a map. University research projects use this HPC and customers often have to wait for their turn to access the computing resource. At the other end of the scale you might find an operation like Netflix, where there is storage but hardly any processing, but enormous quantities of content are delivered. So this data centre would have a high storage capacity, probably lower utilisation but very high levels of digital output as content is streamed.
>
> This operation would perform very well against a bits per Watt metric, but the weather map would perform very badly. The metric would not give an indication of efficiency because the data centres are performing different functions.

As will become apparent in this section, it is difficult to measure and set standards for the environmental performance of data centres which are effective and robust for the wide range of scale and type of applications that this sector covers. The metrics that are widely used, such as PUE, are limited in scope but applied beyond that limited scope in the absence of more appropriate metrics.

Researchers are continuously searching for better metrics and the number of proposed metrics continuously multiply. Recent examples include:

- ICT capacity and ICT utilisation (Newmark et al, 2017)
- Grid Usage Effectiveness (van de Voort et al, 2017b)
- Infrastructure Usage Effectiveness (Wang et al, 2019)
- Energy Eat by Servers and Switches and Energy Eat and Service Level Agreement violation Factor (Shally et al 2019)
- Benchmark Energy Factor, generically for industrial processes (Gosman et al 2013), has been developed specifically for data centres by the Canadian Standards Association in 2021 and published as "CSA C510:21 Ideal state benchmarking and application of benchmark energy factor for data centres"[3]

Reddy et al (2017) reviewed the metrics used as KPIs for sustainable data centres. Table 3, extracted from this paper, includes more than 30 separate energy efficiency metrics which have been proposed.

The paper includes similar listings for other sets of metrics. 137 such metrics were identified for measuring energy efficiency, performance, cooling, storage, and financial impact among others.

Reddy et al argue that, collectively, these metrics do not adequately address data centre sustainability. There is a need for new metrics that consider factors such as the location and age of the data centre, in order to allow comparison across different data centres.

Given this profusion of metrics this section will focus on those which are widely used in the regulations, performance standards and certifications described in Chapter 4. Regulations, performance standards and certifications.

3 Reportedly this was developed as an alternative to PUE and takes into account cooling and IT energy.

Table 3. Energy Efficiency Metrics Overview from Reddy et al 2017

Acronym	Full Name	Unit	Objective	Optimal	Category
APC	Adaptability Power Curve	Ratio	Maximize	1.0	Facility
CADE	Corporate Average Data Center Efficiency	Percentage	Maximize	1.0	Facility
CPE	Compute Power Efficiency	Percentage	Maximize	1.0	Facility
DCA	DCAdapt	Ratio	Minimize	$-\infty$	Facility
DCcE	Data Center Compute Efficiency	Percentage	Maximize	1.0	Server
DCeP	Data Center Energy Productivity	UW/kWh	Maximize	∞	Facility
DCiE	Data Center Infrastructure Efficiency	Percentage	Maximize	1.0	Facility
DCLD	Data Center Lighting Density	kW/ft^2	Minimize	0.0	Facility
DCPD	Data Center Power Density	kW/Rack	Maximize	∞	Rack
DCPE	Data Center Performance Efficiency	UW/Power	Maximize	∞	Facility
DC-FVER	Data Center Fixed to Variable Energy Ratio	Ratio	Minimize	1.0	Facility
DH-UE	Deployed Hardware Utilization Efficiency	Percentage	Maximize	1.0	Server
DH-UR	Deployed Hardware Utilization Ratio	Percentage	Maximize	1.0	Server
DPPE	Data Center Performance Per Energy	Ratio	Maximize	1.0	Facility
DWPE	Data center Workload Power Efficiency	Perf/Watt	Maximize	∞	Server
EES	Energy ExpenseS	Ratio	Maximize	1.0	Facility
EWR	Energy Wasted Ratio	Ratio	Minimize	0.0	Facility
GEC	Green Energy Coefficient	Percentage	Maximize	1.0	Facility
H-POM IT	Hardware Power Overhead Multiplier	Ratio	Minimize	1.0	IT Equipment
ITEE IT	Equipment Energy	Cap/kW	Maximize	∞	IT Equipment
ITEU IT	Equipment Utilization	Percentage	Maximize	1.0	IT Equipment
OSWE	Operating System Workload Efficiency	OS/kW	Maximize	∞	Facility
PDE	Power Density Efficiency	Percentage	Maximize	1.0	Rack
PEsavings	Primary Energy Savings	Ratio	Maximize	1.0	Facility
$PUE_{1\text{-}4}$	Power Usage Effectiveness Level 1–4	Ratio	Minimize	1.0	Facility
$PUE_{scalability}$	Power Usage Effectiveness Scalability	Percentage	Maximize	1.0	Facility
pPUE	Partial Power Usage Effectiveness	Ratio	Minimize	1.0	Facility
PpW	Performance per Watt	Perf/Watt	Maximize	∞	Server
ScE	Server Compute Efficiency	Percentage	Maximize	1.0	Server
SI-POM	Site Infrastructure Power Overhead Multiplier	Ratio	Minimize	1.0	Facility
SPUE	Server Power Usage Efficiency	Ratio	Minimize	1.0	Facility
SWaP	Space, Watts and Performance	Ratio	Maximize	∞	Rack
TUE	Total-Power Usage Effectiveness	Ratio	Minimize	1.0	Facility

Source: Reddy et al 2017

Power Usage Effectiveness

PUE is the most widely used sustainability indicator for data centres. It is defined as:

$$PUE = \frac{\text{total facility energy use over a year}}{\text{IT equipment energy use over a year}}$$

The 'ideal' value for PUE is 1, that is all the energy is used by the IT equipment. The reciprocal of this, Data Centre Infrastructure Efficiency, is also used on occasion, expressed as a percentage.

PUE is not a good measure for comparing energy or resource efficiency between data centres, that is, it is not a reflection of the overall energy, productivity or resource efficiency of a data centre. One reason for this is that the denominator of the equation, the IT equipment energy use, can and does vary significantly depending on the data centre application. Two data centres with the same IT and infrastructure design and equipment will have different IT equipment energy use depending on the applications that they are running and therefore different PUEs.

Appendix 2. Advantages and disadvantages of PUE gives more detail of the pros and cons of PUE as a metric.

The use of other metrics can fill in the gaps in its coverage but the nature of the indicator, as a ratio of total and IT energy use, mean that PUE is limited as an efficiency indicator.

It is of greatest value to colo clients and operators, as it characterises performance in a framework that is largely in control of one party, the colo. For other stakeholders, owners and operators or enterprise or cloud data centres, the focus on PUE, and therefore infrastructure energy use, risks diverting attention from the high energy reductions possible from considering IT energy efficiency more carefully. The lack of a viable alternative metric (which takes into account the IT load productivity) means that PUE will continue to be used as a comparator for many purposes, some of which it is not truly suitable for, for the foreseeable future.

PUE was originally proposed as a metric by the Green Grid[4] in 2007 (The Green Grid 2016) to track the effect of changes to the data centre structure or operation; that is, to track performance over time. It has been formalised in measurement standards, EN 50600 4:2 and ISO/IEC 30134-2. Both standards have three categories of ratings, depending on the resolution of the energy performance data, with category 1 being basic, 2 intermediate and 3 advanced. The resolution category is expressed as a suffix to the value, e.g. PUE_3. ISO/IEC 30134-2 (2016) explicitly states "PUE should not be used to compare different data centres."

Nonetheless, it has been adopted by the industry to compare the performance of different data centres, irrespective of their scale, usage or locations. Consequently, PUE has been incorporated in many performance standards and ratings.

Other KPIs used in performance standards and certifications

Other metrics have been developed which are complementary to PUE and which are used in one or more of the performance standards or certification schemes outlined in Chapter 4. Regulations, performance standards and certifications. Most of these relate to energy in some way. They are:

Renewable Energy Factor (REF)

This is the ratio of the renewable energy owned and controlled by a data centre to the total data centre energy consumption.

$$REF = \frac{\text{Renewable energy supplied to data centre}}{\text{Total data centre energy use}}$$

Energy Reuse Factor (ERF)

Energy Reuse Factor is defined as (Patterson et al 2010):

$$ERF = \frac{\text{Reuse energy}}{\text{Total data centre energy use}}$$

Where reuse energy is energy that is used outside the data centre. ERF will range from 0 to 1.0. The value at 0.0 means NO energy is reused, while a value of 1.0 means all of the energy brought into the data centre control volume is reused.

The same information can also be expressed as the Energy Reuse Effectiveness (ERE) which is defined as:

$$ERE = (1 - ERF) \times PUE$$

This value expresses how data centre waste energy is used by other parts of a facility, or in nearby buildings such as offices, homes, restaurants, hotels, greenhouses and swimming pools.

Carbon Usage Effectiveness (CUE)

Carbon Usage Effectiveness is defined as (Belady et al 2010):

4 The Green Grid is an affiliate membership level of the Information Technology Industry Council (ITI), a trade association for the tech sector.

$$\text{CUE} = \frac{\text{Total CO}_2 \text{ emissions caused by the Total Data Center Energy over a year}}{\text{IT equipment energy use over a year}}$$

With units of kilograms of carbon dioxide (kgCO2eq) per kilowatt-hour (kWh).

Alternatively it could be expressed as the Carbon Emission Factor of the energy supplied to the data centre multiplied by the PUE.

Water Usage Effectiveness (WUE)
Water Usage Effectiveness is defined as (Patterson et al 2011)

$$\text{WUE} = \frac{\text{Annual Water Usage}}{\text{IT equipment energy use over a year}}$$

With units of litres/kilowatt-hour (L/kWh).

There are two variants to this: WUE – which covers site water usage, and WUE_{source} a source-based metric that includes water used on-site and water used off-site in the production of the energy used on-site. Typically, this adds the water used at the power-generation source to the water used on-site (similar to carbon Scope 2). The latter metric allows for the fact that with conventional cooling water use reductions on site generally have adverse trade-offs with increased energy use and therefore increase water use at the source of the energy generation.

Mytton (2021) reviews the data on water use, use of non-potable and recycled water and other industry approaches to reduce water use.

HVAC specific
The energy performance of HVAC components of data centres referred to in the regulations, certifications and agreements included in this report are:

- Energy Efficiency Ratio (EER): the ratio of the cooling capacity to the electrical energy input (the higher the EER the more efficient the equipment)
- and Coefficient of Performance (COP): the ratio of useful cooling provided to the energy input (the higher the COP the higher the efficiency)

The different technologies used for data centre cooling are described in brief in the section Current and developing practice in cooling.

Service level related
Data centre service levels are classified in EN 50600-1 and ISO/IEC TS 22237.

Server metrics
The main metrics used are the IT equipment energy efficiency for servers and IT equipment utilisation for servers.

The former is frequently measured using ISO/IEC 21836, which uses the Server Efficiency Rating Tool[5] (SERT™), a commercial tool which can be purchased from the Standard Performance Evaluation Corporation. It assesses the energy efficiency of computer servers using reliable, accurate and reproducible measurement methods. It is used in the EU and Japanese computer standards and for the ENERGY STAR voluntary certification, as listed in the regulations and certifications section.

The IT equipment utilisation for servers, ITEUsv, is used as one of the Blue Angel eco-label requirements. It is one of the set of KPIs defined in EN 50600 4 and ISO/IEC 30134 series of standards (see Table 10 for the complete listing). It describes the utilisation of the server equipment in the data centre in operational conditions. ITEUsv was developed in acknowledgement of the fact that server energy efficiency tends to be optimal with higher utilisation level. ITEUsv accounts for utilisation (the amount of time the server is actually doing work) and power management (the ability of the server to reduce the energy consumption when the server is not fully loaded) aspects.[6]

2.3 Transparency of data centre energy performance reporting

This section explores the extent and process of data centre energy performance reporting, what the reported data showed about performance, and how practices in countries vary.

Sources of data
Publicly available datasets on energy performance for any jurisdiction are limited. It is recognised that this does not support initiatives which are trying to increase sustainability. Alsop (2021) identified that "Before the data centre industry as a whole embarks on a major sustainability drive guaranteed to produce major, positive changes, there's no doubt that a better picture of what is, or isn't, going on in the current global data centre population is all but essential".

5 For details see the SERT page of the SPEC website
6 Source: the ISOIEC-30134-00 factsheet on the ICT Footprint website. ICT Footprint was funded by the European Commission H2020 programme

Typically, commercially owned or operated data centres do not publish energy performance data as they are commercially sensitive: for most, energy costs are their largest single operating cost. However, no evidence was found of any government requiring[7] energy reporting by private sector data centres, even if that data were kept private.

Publicly available information includes:

- Statistics Netherlands has published data on the electricity supplied to data centres for 2017–2019[8] based on data provided by network operators.
- In the US in 2018 the Energy Information Administration undertook a pilot for adding data centres as a separate building type to their periodic Commercial Buildings Energy Consumption Surveys (Energy Information Administration 2021) but found that obtaining data centre estimates was likely not feasible with current methods.

Further focused searches failed to uncover data on public (central or local Government) energy use.

Some initiatives collect these data, for example the EU Code of Conduct and the US DCOI, but only rarely or partially publish the results.

The data that have been found are limited and are generally reported in terms of PUE. These were largely identified as auxiliary references in the initial literature search for metrics and policies, although some were found in the dedicated search.

Findings

The data on energy performance are presented by geographic region in Appendix 3. Energy performance data.

These are very sparse and in most cases they are not for the whole market: e.g. only from the largest operators in the market or members of an association or agreement. It is not possible to draw any conclusions on performance by region or size or type of operation based on these data. It is clear that there is, in general, a lack of transparency and at least some parts of the industry recognise that this is a barrier to increasing data centre sustainability.

7 Some voluntary schemes include data declaration, for example the UK Climate Change Agreements, described below.

8 Statistics Netherlands, Netherlands Electricity supplied to data centres, 2017–2019, 16th April 2021

3. Practices and trends in data centres

This section describes the current situation and predicted trends in data centre operation, impacts and locations.

3.1 Ownership and operation

Changes in operation and scale – the move to the cloud and hyperscale[1]

Concentrated IT resources started initially as server rooms in organisations and then grew to become full data centres in enterprises. With the development of the internet and increasing ecommerce large stand-alone data centres were built, as co-location spaces and latterly as dedicated cloud resources. This process of concentrating more data processing power in fewer, larger data centres is known as consolidation.

There are pros and cons to organisations siting their IT on-premises or outsourcing to third parties. Ascierto and Lawrence (2020b) list these (see box below).

The author would add that large scale data centres can have advantages in terms of increased energy efficiency and reduced carbon emissions. As these are broader societal benefits they can also be included in an organisation's Corporate Social Responsibility (CSR) reporting, or against carbon reduction targets.

In response to these advantages, and possibly to other trends in the type of data centre usage (such as streaming of TV content) in the last ten years, data centre capacity and energy use have shifted from those owned and operated by companies (enterprise), largely small scale,

Factors driving outsourcing to third-party data centre services:

- **Cost:** Outsourcing can lower costs in the short to medium term. For organizations "born" in a public cloud or Colo, it typically is too expensive to move to an enterprise data centre.
- **Cost allocation:** Outsourcing shifts cost allocations from capex toward more repeatable opex models.
- **IT agility and flexibility:** Outsourcing provides the ability to readily and quickly adapt to changing capacity needs without the burden of managing the full stack of IT and applications; IT can be used for a project's duration only (e.g., for test and development).
- **Access to resources:** Third parties may provide access to a wider range of resources, including technology, interconnections, software tools, services and application environments.
- **Security:** Third parties can offer the most advanced, highly resourced security features.

Factors driving demand for on-premises enterprise data centres:

- **Cost:** Ownership delivers total cost of ownership benefits over the long term; in the shorter term, owners avoid the data transport costs of moving to an outsourced venue.
- **Governance:** On-premises environments may be necessary for compliance with data governance and regulatory requirements.
- **Control:** Owners can closely monitor and control factors such as latency, availability and application performance. While most outsourced venues are strong in these areas, service level agreements vary and are limited.
- **Risk:** Ownership ensures full visibility into (and the ability to adjust) the risk profile of every workload.
- **Security:** Ownership provides the ability to maintain control and governance (dedicated rather than shared physical infrastructure) over security features.

1 There is no universal definition of what constitutes a hyperscale data centre. Market intelligence firm International Data Corporation are reported as generally defining a data centre as "hyperscale" when it exceeds 5,000 servers and 10,000 square feet (from "What is a Hyperscale Data Center?", Chrissy Kidd, July 2018, BMC.

Figure 3. Global data centre energy demand in TWh by data centre type, Kamiya and Kvarnström (2019)

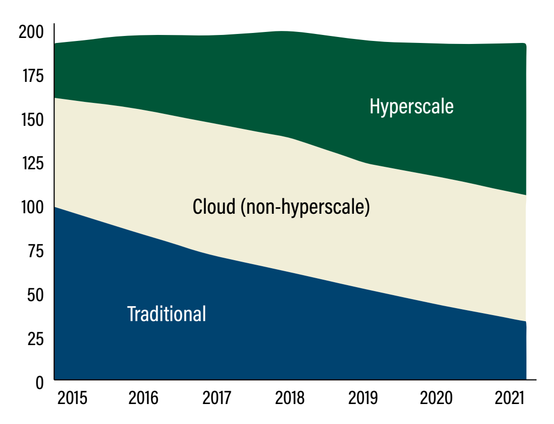
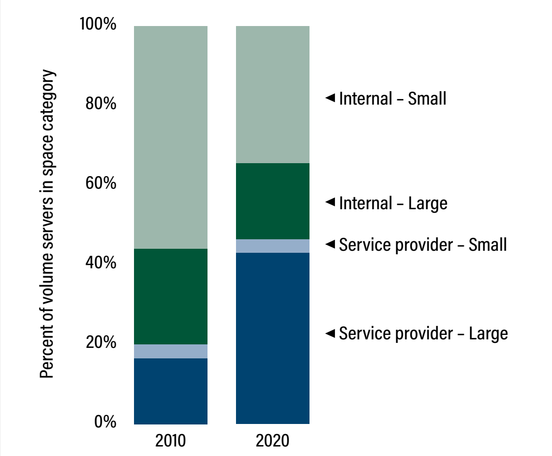


Figure 4. Distribution of server installed base across four space categories, 2010 and 2020 in the USA. Data centers with floor space greater than 1850 m^2 (enterprise and hyperscale size categories) are represented as large. Shehabi et al (2018)



to cloud and hyperscale (i.e. greater consolidation). One international illustration of this trend expressed as energy demand is in Figure 3 (Kamiya and Kvarnström 2019).

The split, expressed in data centre capacity rather than energy, between small and large scale and internal and external service for the USA is shown in Figure 4 (Shehabi et al 2018)

This evidence for a shift to large scale is supported by a report from Arcadis (2021) "there are now more than 650 hyperscale data centers around the world. That's more than twice the number in existence in 2015, when there were only 260". This trend is expected to continue, at least in the short term (Ascierto and Lawrence 2020b).

Hyperscale data centres in particular are known to operate with high efficiency. Bizo (2019) attributes this to the fact that "cloud operators make the entire technical organization work in unison to attain high infrastructure efficiency by design, while the cloud business model of a shared and monetized infrastructure drives server utilisation well above what is possible for enterprises".

He asserts that most of the energy savings come from two factors specifically: a more energy efficient server population and much higher server utilisation (these factors are discussed in Other ways of reducing environmental impact below). This is in contrast to the frequent references in the literature and promotional articles to low infrastructure energy use in such data centres, resulting in low values of PUE.

The increase in cloud, in particular hyperscale, data centres as a proportion of the total is widely accepted as having contributed to the flattening of data centre energy use, see for example Masanet et al (2020) reported in the section Data centre energy use estimates 2010–2018 below. This is due, at least in part, to the fact that efficiency is a key contributor to reduced costs and increased profitability for tech companies who specialise in providing data services.

Future trends – the move to the edge

Alongside the consolidation of data in larger data centres, and to some extent driven by it, there is a growing requirement for data processing and storage near where data are generated and/or consumed – referred to as edge computing.[2] The main driver behind this is applications which require low latency; that is, very quick reactions between the user (human or IT) and the data centre. Other, significant but less important, factors include autonomy, security and privacy (Linux Foundation 2020). Shi et al (2019) also list security and privacy as drivers of edge computing. However, other researchers consider that edge computing presents new challenges in these areas, (Munn (2020) presents concerns on the effect of privacy regulation and Ranaweera et al (2019) on security.)

The types of applications which require low latency include: the Internet of Things (IoT), 5G, Artificial Intelligence (AI), Virtual Reality (VR), and Augmented Reality (AR). These are used in a variety of settings including manufacturing, retail, gaming, telemedicine, remote

2 Linux Foundation (2020) define edge computing as the delivery of computing capabilities to the logical extremes of a network in order to improve the performance, security, operating cost and reliability of applications and services

learning, and blockchain. Demand for these applications is expected to grow strongly.

Forecasts of the growth in edge computing capacity and energy use differ widely, reflecting the uncertainty in the speed of uptake. Currently capacity is thought to be less than 10% of 'conventional' data centres. Some, bullish, projections have Compound Annual Growth Rates much higher than for the latter, resulting in capacities in 2028 of several times the current conventional capacity (these are described in Appendix 4. Edge data centres).

There is a continuum of locations for edge computing but several experts have grouped them into two: the local edge and network edge (see, for example Ascierto and Lawrence 2020b). The former is sited within a kilometre or two of the point of use, providing the lowest latency via micro data centres; and the latter a short to medium distance away, with low to medium latency via telecommunications companies[3] (Telcos), Colos and Content Delivery Network (CDN) points of presence (PoPs). The local edge is more distinct from conventional data centres, in terms of scale and physical characteristics and is therefore the focus of attention.

Local edge data centres are usually stand alone, may be sited remotely and are generally smaller and more numerous than conventional data centres. This may mean that operating them to the same high energy efficiency and reliability standards expected of conventional data centres is more of a challenge.

There is a risk that, if the more optimistic market projections are correct and sustainability aspects are not sufficiently taken into consideration, the environmental impact of edge computing could exceed that of conventional data centres. The author has not been able to find any evidence of policy intervention or regulation specific to edge computing to date; in principle the same rules apply as for conventional data centres, irrespective of size.

Information from the literature on the applications, nature and market of edge computing is in Appendix 4. Edge data centres.

3.2 Projections of market size and energy usage

Data on data centre market size may be expressed in a number of metrics, including: floor area in m^2, provisioned power[4] in MW or turnover expressed in local currency. Each of these has its advantages in a particular context but none of them is wholly descriptive of the market. The author was unable to identify any projections of market size which are sufficiently robust to include in this report.

Estimates of energy use by data centres do exist, at least in part driven by the widespread concern about the potential increases in energy use and the associated GHG emissions referred to elsewhere in this report. A selection of projections to 2030 (there are none that project beyond 2030), are presented in Appendix 5. Market data and projections by region, for China, Europe and globally. The two examples of global projections are by the same authors and give a wide range of values depending on scenarios, reflecting the uncertainty in both the increase in data traffic and the scope for further increases in energy efficiency.

3.3 Current and developing practice in cooling

Conventional cooling

Most data centres operate with variations on 'conventional' air conditioning systems, a combination of chillers and air handling units to cool, control humidity of and then circulate forced air.

Good practice for this approach is well established and understood, although not necessarily widely applied. For example Turner et al (2014) outline the following as steps to take in achieving best practice:

- improve cooling air management. For example:
  - arrange the IT equipment into Cold Aisles and Hot Aisles (only the air intake to the computer hardware is required to be cold)
  - with raised floor cooling placing perforated floor tiles immediately adjacent to the front of the rack they are cooling
  - seal holes such as cable holes and use blanking plates to avoid air flow through empty racks and spaces in racks between servers
- fit air temperature sensors and implement supply air control
- increase operating temperatures (in line with ASHRAE Technical Committee (TC) 9.9 thermal guidance– as discussed in the standards section)

3 Who have distributed resources as a result of the nature of their business.

4 Maximum power capacity

– increase the allowable humidity range to lower humidification/dehumidification needs

– use variable speed cooling fans

– increase chilled water temperature

Expert reviewers suggested two additional steps:

– The use of soft starters, Electronically Commutated fans, and Variable Speed Drives combined with harmonic filtration on all motors, fans, pumps and compressors

– The use of limited bends within all mechanical cooling pipe work and A/C ductwork

Responses to surveys from Uptime Institute to that point suggested that most respondents were not following good practice.

Each of the good practice steps listed above can reduce energy consumption significantly while maintaining operational conditions for the IT equipment, and may improve them, for example by eliminating hot spots. For new data centres it may be cost effective to customise air flow using Computational Fluid Dynamics (CFD) to model different arrangements (for example Almoli 2013).

Free air cooling can be used when the external temperature (strictly the server inlet temperature) is less than 27 C, with the use of air or water economizers (one of many suggestions in Bruschi et al 2011 and ASHRAE Technical Committee (TC) 9.9 Thermal Guidance).[5] Some researchers have experimented with direct air free cooling in a tropical climate (Singapore, Le et al 2020). Using air filtration and forced air cooling only when the ambient temperature exceeded 31C they were able to maintain ASHRAE A3 conditions (see Temperature and humidity tolerances sub section above for description) for temperature and humidity and make substantial energy savings.

New developments

Liquid can transfer heat more effectively than air, offering the potential for higher energy efficiency, resulting in lower operating costs. To date liquid cooling has not been widely adopted, possibly because of higher capital costs and lower familiarity, although operators have also expressed concerns about safety and reliability. Processing chips with higher power density and faster data transmission are driving the adoption of servers with increasingly higher energy density, which air cooling struggles to manage effectively. This means that liquid cooling is expected to become a necessity in some applications (Copenhagen Centre on Energy Efficiency, 2021).

Liquid cooling can also have the added advantages of lower (or no) water use and result in higher outlet temperatures, increasing the feasibility of recovering waste heat that can be reused via a district heating network or other local use such as greenhouses or swimming pools (Sartor et al 2019). The scope for re-use of waste heat from data centres, whether air or liquid cooled could be extensive. For example Wegner et al (2021) estimated heat energy savings of 1.5 GW (13 TWh p.a.) from data centres and cable tunnels in London.

There is a range of technologies whereby water, or a specially formulated liquid, can be used as a coolant, with different degrees of integrating the cooling liquid into the server architecture: from cold plates (where cold liquid is circulated in a plate above the server, or next to the CPU), to integrated (where liquid pipes run on the rack for use inside the server enclosure) (Sartor et al 2019).

A more comprehensive approach is immersion cooling, where computer components or full servers are immersed in a thermally, but not electrically, conductive liquid (a dielectric coolant, which may be a mineral oil or synthetic fluid). This can be single phase; the liquid coolant is circulated and passed through a heat exchanger to cool it. Or it could be two phase–the liquid boils, with the resulting gas condensed and recirculated (Pope D 2021).

Advantages for immersion cooling beyond other liquid cooling approaches can be (Sartor et al (2019), Copenhagen Centre on Energy Efficiency, (2021), CGG (2021)):

– eliminating water use;

– reducing server energy use (no fans are required within the rack);

– removing the need for raised floors;

– less floor space (space not required for the pipes and/or air handlers and/or cooling towers and it is possible that the IT equipment can be more tightly packed);

– a quieter working environment;

– increased reliability (the server is sealed in a unit so is no longer affected by vibration, air humidity or airborne dust particles);

5 Some experts noted that if the ambient air is highly contaminated the energy cost of filtration may come close to, or exceed, the energy savings from free air cooling.

– fewer working parts so less maintenance required.

Sartor et al (2019) state that the fact that most immersion cooling solutions are unique and proprietary has proved a barrier to the widespread adoption of immersion cooling. Another barrier is concern about spillages.

In ITU-T L.1305 the ITU (2019) suggests that the use of Artificial Intelligence (as part of infrastructure management software) can help to increase the efficiency of cooling in data centres.

The significance of data centre cooling in terms of operational costs and environmental impact is made clear when considering that more radical approaches have been or are being tested including:

– siting a data centre on a barge in a river[6]

– using sea water for cooling[7]

– siting a data centre on the sea bed[8]

– siting edge units on water heaters in people's homes[9]

3.4 Other ways of reducing environmental impact

Using more efficient server and data storage equipment

It is advisable to install servers and data storage with high energy efficiency in a new data centre (Huang and Masanet 2017). Bashroush and Lawrence (2020) go beyond this and suggest that operators of existing data centres should consider replacing older servers. IT energy efficiency has generally increased at the same rate as the number of transistors in a dense integrated circuit (doubling every one and a half years, known as Moore's Law (Koomey et al (2011). The possible energy savings from server replacement are outlined in Appendix 6. Energy savings from replacing older servers and operating with higher utilisation.

6 Port of Stockton, California.
7 News story on Data Centre Dynamics website, Google to invest $670m to build a second data center in Hamina, Finland, May 2019.
8 Microsoft, off Scotland's Orkney Islands, news story on Microsoft website, September 2020.
9 In the UK, Heata.

Huang and Masanet (2017) suggest the following options for improving the efficiency of data storage equipment using:

- lower speed drives
- massive array of idle disks, particularly for data accessed infrequently
- solid-state drives
- equipment which is certified as energy efficient (for example ENERGY STAR compliant).

Infrastructure energy use (for cooling and power supply) should reduce broadly proportionally with IT energy use,[10] so energy savings from more efficient IT can be multiplied approximately by the PUE. However these additional savings will only be realised if power and cooling equipment are adjusted or re-sized to account for the reduced IT power load, which is not always the case.

Some researchers have pointed out that replacing IT equipment may reduce sustainability, depending on the circumstances, due to the emissions embodied in the equipment (see for example Flucker et al 2018).

Managing servers and data storage equipment to work more efficiently

Server virtualisation is one of the main tools used to operate servers more efficiently. Virtualisation enables multiple virtualised data centres to be hosted on the same physical infrastructure, which can simultaneously be used by separate applications and/or organisations. This not only helps in optimal IT infrastructure/resource utilisation, but also in reducing data centre capital and operational costs. It can be used in any form of data centre but is applied most widely in cloud computing. (Huang and Masanet 2017).

Other IT operational best practices suggested by Acton et al (2021) and General Services Administration (2016) include:

- enabling power management features on servers and data storage
- decommissioning and removing unused equipment
- determining the business impact of service incidents for each IT service and deploying only the level of Business Continuity / Disaster Recovery standby IT equipment and resilience that is fully justified by the business impact.

Renewable Energy purchase

Kamiya and Kvarnström (2019) note that ICT companies are major investors in renewable energy, thereby protecting themselves from volatile power prices, reducing their environmental impact and improving brand reputation. They report that hyperscale data centre operators in particular are leaders in corporate renewables procurement, particularly through power purchase agreements.

Some companies are now offering specialist services, arranging purchase of renewable electricity for data centres (see for example Tempest 2020).

The concern around reputation has been driven in part by environmental NGOs tracking and reporting on their progress and drawing up league tables of companies' performance (see for example Greenpeace USA 2017 and Greenpeace 2021a).

Google is a notable corporate exemplar; in 2018 they stated their aspiration of sourcing carbon-free energy 24 hours a day, seven days a week.[11] More recently, Google have been trialling time-shifting of non-urgent computing tasks (like adding new words to Google Translate) to periods when supply of renewable electricity is most plentiful (Radovanovic et al 2021); and shifting (non-sensitive) computing tasks across geographic locations to where supply of renewable electricity is most plentiful[12] in order to minimise the carbon intensity of their energy use.

3.5 Current major data centre locations and factors influencing location

Detailed information on current centres of data centre location and the factors influencing the choice of location are in Appendix 7. Data on current locations and factors affecting choice of location. The findings are synthesised here.

Current main locations

The USA has the greatest concentration of data centres. Different sources list a range of major hubs, between seven and ten, all near major conurbations, with Northern Virginia (close to the centre of US Federal government in Washington DC) having the greatest concentration (measured by capacity).

10 Provided power and cooling equipment are adjusted to account for the reduced IT power load.
11 Google blog, Michael Terrell, October 2018, The Internet is 24x7. Carbon-free energy should be too.
12 Google blog, Ross Koningstein, May 2021, We now do more computing where there's cleaner energy.

Europe is also a big market, with four longstanding major hubs: Frankfurt, London, Amsterdam, and Paris (abbreviated as FLAP), of which London is the largest. Dublin is now often added to that list and markets are developing rapidly in the Nordic countries (Sweden, Norway, Finland, Denmark and Iceland) who are competing aggressively for new data centres to be built there.

In Asia, China is the major market with Shanghai as a hub; other Asian centres include Singapore, and Tokyo. The centres in Australia are Sydney and Melbourne.

Cisco are reported in Kamiya and Kvarnström (2019) as stating "nearly all hyperscale data centres are located in three regions: North America (46%), Asia Pacific (30%), and Western Europe (19%)"

Factors influencing location

The literature search has unearthed many factors (see Appendix 7. Data on current locations and factors affecting choice of location for details). Some of these, relate to access to:

- the market (companies and consumers)
- high speed and reliability of digital networks
- reliable electricity networks
- expert staff

Another criterion is being in the same jurisdiction as the data owner for data protection reasons.

All of these favour placing data centres in large urban and/or business and/or government centres. The current market distribution (as outlined above and described in more detail in Appendix 7. Data on current locations and factors affecting choice of location) suggests that they have been the dominant factors to date. Going against this trend is the fact that land costs in these locations are likely to be high.

Other considerations are those which would occur with any investment, particularly those involving construction. These include legal and permitting regimes, costs (land and operational), taxes, incentives and political stability. Dublin's increasing suitability as a location is seen as having been in response to these factors.

However, there are factors related to sustainability which have become more important in recent years: climate (cold climates increasing the opportunity for free air cooling), easy/close access to renewable electricity sources (reducing carbon emissions), and, to a lesser extent, unlimited water supplies (for cooling) and access to markets for waste heat (to improve sustainability). The success of the European Nordic countries in the last few years suggest that these factors, together with associated reduced operating costs, are having an effect on owners' and customers' decisions.

The consensus seems to be that the trend to build new hyperscale data centres in areas where sustainability is higher is likely to continue, but not to the exclusion of new capacity being built in existing centres.

4. Regulations, performance standards and certifications

The evidence suggests that government regulation of the energy efficiency of data centres is sparse. There are reports in the press of Singapore 'banning' development of new data centres due to concern about their high environmental impact.[1] Similarly there are news reports of cities having imposed bans, (Amsterdam in the Netherlands[2]) Research has not found official documents related to these bans. The Irish government has said that it is considering placing restrictions on data centre building, in order to meet targets for emissions and renewable energy.[3]

China is thought to be the only country which will require existing and new data centres to meet performance standards (expressed in PUE, announced in October 2021, to take effect from 1 November 2022[4]).

There are regulations, voluntary certifications and voluntary labels for components of data centres: servers, data storage and HVAC in other countries – summarised in Table 4.

Prior to the Chinese announcement data centres as a complete operational unit lacked direct energy efficiency regulation, however, there are a plethora of voluntary labels, rating and certification schemes. Table 5 shows the certification schemes and labels for data centres which include energy efficiency as a criterion, which were identified in the course of this research. One of these is an existing scheme with criteria specific to data centres (marked pre-existing in Table 5); most have been developed specifically to data centres (marked specific in Table 5). There is a mix of organisations who manage these schemes, some

Table 4. Component regulations and labels

Name	Geographic coverage	Type of initiative	Lead organisation type
Building Energy Efficiency Standards for Residential and Non-residential Buildings, Title 24, Part 6, (HVAC systems for data centres)	California	Building code	Government
EU Ecodesign regulations for servers and data storage products 2019/424	EU	Minimum Energy Performance Standard	Government
EPEAT for servers NSF/ANSI 426–2019	International	Graded ecolabel	NGO
Energy Code 2018 Section: C403.1.3, Data Centers (HVAC and electrical loss component)	Washington State	Building code	Government
Energy Conservation Standards for Electronic Computers Public Notice of the Ministry of Economy, Trade and Industry No. 69	Japan	Minimum Energy Performance Standard	Government
ENERGY STAR Computer Servers Version 3	USA	Energy efficiency endorsement label	Government
EC DG JRC Code of Conduct for Uninterruptible Power Systems	EU	Voluntary code of conduct	Government
ENERGY STAR Uninterruptible Power Supplies Version 2	USA	Energy efficiency endorsement label	Government

1 Data Center Dynamics article, Paul Mah, January 2021, Cracking the green conundrum in Singapore, amid a data center moratorium.
2 Data Center Dynamics news item, Peter Judge, July 2020, Amsterdam resumes data center building, after a year's moratorium.
3 Reported by Data Centre Dynamics Nov 2021
4 Reported by TUV Sud November 2021

Table 5. Overview of data centre efficiency ratings, certifications or labels which account for energy efficiency

Name	Pre-existing (P) or DC Specific (S)	Endorsement (E) or Grades (G)	Geographic coverage	Lead organisation type
Blue Angel	P	E	Germany	NGO
Certified Energy Efficient Data Center Award (CEEDA)	S	E	International	Commercial
DCA (Data Centre Alliance) Certification Scheme	S	E	International	NGO
Fossil Free Data	S	E	Sweden	Commercial
Green Data Centre Standard SS 564	S	E	Singapore	Government
Swiss Data Centers Efficiency Label	S	G	Switzerland	Trade association[a]

a The Swiss Data Centers Efficiency Association, an alliance of industrial and academic organisations.

Table 6. Overview of building based data centre efficiency ratings, certifications or labels which account for energy efficiency

Name	Pre-existing (P) or DC Specific (S)	Endorsement (E) or Grades (G)	Geographic coverage	Lead organisation type
BCA-IDA Green Mark for Data Centres	S	E	Singapore	Government[a]
BEAM Plus New Data Centres	P	G	Hong Kong and some regions of mainland China	Trade association
BEAM Plus Existing Data Centres	P	G	Hong Kong and some regions of mainland China	Trade association
BREEAM data centres SD 5068	P	G	UK	Commercial
Energy Conservation Building Code (ECBC) in Data Centers	P	G	India	Trade association
ENERGY STAR	P	G	USA	Government
Green Building Index (GBI) for Data Centers	P	G	Malaysia	Trade association
Indian Green Building Council Data Center rating system	P	G	India	Trade association
LEED for building design and construction Data Centers and O+M: Data Centers	P	G	International	Trade association
NABERS	P	G	Australia	Government

a jointly developed by Building and Construction Authority (BCA) and the Infocomm Development Authority (IDA).

Table 7. Other data centre initiatives

Name	Geographic coverage	Type of initiative	Lead organisation type
Climate Change Agreement for the Data Centres Sector	UK	Industry voluntary agreement	Government
Climate Neutral Data Center Pact	EU	Industry voluntary agreement	Trade association with Government involvement
Data Center Accelerator[1] and the Better Buildings Challenge	USA	Voluntary high-performance recognition initiatives	Government
Data Center Optimization Initiative (DCOI)	USA	Rules and guidance for ownership and operation of Government data centres	Government
EC DG JRC Code of Conduct for data centres	EU	Voluntary code of conduct	Government
Proposal for a Directive on Energy Efficiency (recast)	EU	(draft) Disclosure requirement	Government
Energy Saving Obligation – commercial data centers	Netherlands	Industry EE requirement	Government
EU Green Public Procurement (GPP) criteria for Data Centres	EU	Public sector procurement criteria	Government
France finance law 2021 provisions for data centres	France	Tax rebate	Government
New South Wales Government Resource Efficiency Policy	Australia	Procurement requirement	Government
Sustainable Public Procurement guidance for Networks, Telephone Services and Telephone Equipment[2]	Netherlands	Public sector procurement criteria	Government
Three Year Plan for new data centers	China	Policy	Government
USA Federal Data Center Optimization Initiative	USA	Policy	Government
USA Federal Open Data Initiative	USA	Policy	Government

1 Completed so no longer active
2 Includes data centres

are Government led, and others have been developed by NGOs, trade associations or commercial companies. Within these there is a further distinction: most are 'simple' endorsement labels (the qualifying data centre meets the required criteria), one has grades for different levels of performance.

Table 6 shows the equivalent listing for building based schemes which have developed specific data centre criteria. In this case most of the labels are pre-existing, only one has been developed specifically for data centres and most of the labels award grades, with only one a 'simple' endorsement label.

In addition to these there are a number of other initiatives which do not fit into these categories but are still an important part of the data centre certification landscape, listed in Table 7. These vary widely in technical coverage and rigour; all are government led or have a strong association with government.

More information on all these initiatives is in Appendix 8. Descriptions of regulations, certification and other initiatives.

4.1 Evidence on the effectiveness of metrics, policies and certifications and market changes

There is little evidence on the effectiveness of the metrics, policies and certifications described in this report.

A targeted search of the literature was undertaken to try to find assessments or evaluations of the metrics, policies and certifications described in this report. Keyword searches were made of the internet using Google scholar and of the extensive library of grey and white literature held by the Association for Computing Machinery[5] with no satisfactory results. The conference proceedings of the European Council for an Energy Efficient Economy, American Council for an Energy Efficient Economy, Energy Evaluation Europe, Energy Evaluation Asia Pacific and the International Energy Program Evaluation were also searched back to 2016 or 2017- again with no results.

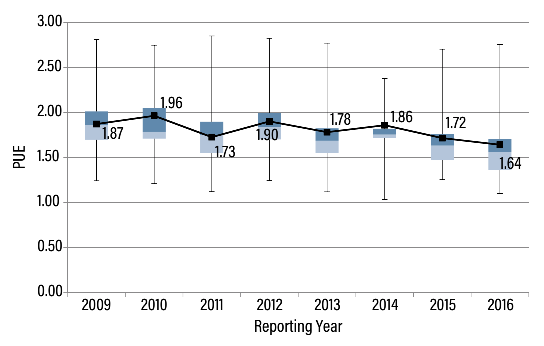
A number of these policies or certifications have only been adopted relatively recently (e.g. the LEED for data centres, Indian Green Building Council Data Center rating system, Blue Angel, EU Green Public Procurement). Others serve commercial purposes and might not be expected to make data public or publish assessments (e.g. Certified Energy Efficient Data Center Award).

Where evidence has been found, these are described below.

EU Code of conduct

Avgerinou et al (2017) described trends in energy use and energy efficiency as reported by participants in the EU Code of Conduct (CoC) to the end of 2016. At this point there had been 345 applications to join, most from within Europe, with a handful from elsewhere (the USA and Mauritius). They presented an analysis of data from a subset of these, 289 data centres that had been approved and had submitted complete energy data. They reported a small but statistically significant reduction in reported PUE over the period of the CoC operation from 2009 to 2016, as shown in Figure 5. They found no statistically significant variation in PUE by period of construction, size by floor area or size by IT rated loads.

Figure 5. EU Code of Conduct participant reported PUE by year from Avgerinou et al (2017).



UK Climate Change Agreements

Participants in the Climate Change Agreements (CCAs) have to report their progress against targets at specified periods, generally every two years. The data from the most recent published report, in 2018,[6] shows the data centre sector achieved an improvement in energy performance of 16.8% which exceeded their target for that period. For the next period, 2020, the target was a 15% reduction in PUE (techUK 2017). This evidence suggests that the CCA is achieving targets for reducing infrastructure energy use.

The UK Government department for Business, Energy and industrial Strategy, which has responsibility for this policy, recently published an evaluation of the CCA scheme (BEIS 2020). This evaluation concluded that the policy had

Table 8. Performance by agency against DCOI performance metrics reported in Fiscal year 2019

Metric	Number met	Number did not meet	Number not applicable
Virtualisation	11	7	6
Availability	16	2	6
Advanced energy metering	11	7	6
Under utilised servers	12	6	6

5 Association for Computing Machinery Digital Library.
6 Climate Change Agreements–Sector Performance Data, published by: Environment Agency.

made a contribution to increasing the energy efficiency and competitiveness of participants overall, although this varied considerably for specific firms. The evaluation did not draw specific conclusions on the data centre sector (there are 50 sectors involved in the scheme).

USA Federal Data Center Optimization Initiative

The US Government Accountability Office[7] (GAO) reviewed progress on the Federal Data Center Optimization Initiative (DCOI) (Government Accountability Office 2021). They found that the 24 Federal agencies which participate in the Initiative continued to make progress on their targets for consolidating data centres, closing redundant ones and saving costs. In the Fiscal Year 2019[8] progress towards targets on metrics was as shown in Table 8.

GAO noted that agencies have been asked to develop their own methodology for evaluating server utilisation that addressed their individual mission and hardware and software needs. Their review found that some agencies' methodologies might not provide an accurate view of their data centre optimisation progress. They recommended that the Office of Management and Budget should reexamine its guidance regarding how to measure server utilisation and revise it to better and more consistently address server efficiency.

Also the U.S. Government's IT Dashboard[9] provides statistics on federal agency data centre DCOI goals including virtualisation, metering and utilisation, by Government department or agency, which are updated quarterly.

4.2 Data centre energy use estimates 2010–2018

Information on data centre capacity and energy use is rare and tends to be for sub-selections of the global market, such as the US (Shehabi et al 2018). An exception is Masanet et al's (2020) article in Science; this provides estimates of global data centre capacity and energy use in 2010 and 2018 and projections of both to the near future. This is reported here to provide context.
Their data suggest that while data centre capacity, traffic and compute instances increased substantially between 2010 and 2018 (by factors of 26, 11 and 6.5 respectively) the energy use increased by 6%, from 194 to 205 TWh. They found that the energy intensity of global data centres, expressed as energy use per compute instance, has decreased by 20% annually since 2010. They attributed this increased efficiency to a combination of IT efficiency improvements and lower infrastructure energy use (improved PUE). They assert that some of the efficiency gains come from technology improvements, such as server efficiencies and others from structural changes, such as greater virtualisation and the move from smaller to hyperscale data centres.

4.3 Challenges in developing policies for data centres

It has been identified that the challenges in developing policies for data centres include:

– the wide range of size and type of applications, with rapidly changing dynamics

– fast moving technology

– the international market for cloud services which means that there is global competition (potential for 'leakage' if regulation in one jurisdiction is considered too restrictive)

– high requirements for reliability and availability in some applications (although these are not mutually exclusive with improved energy performance / reduced environmental impact).

7 A legislative branch government agency that provides auditing, evaluation, and investigative services for the United States Congress. It is the supreme audit institution of the federal government of the United States.
8 October 1, 2018 through September 30, 2019.
9 DCOI dashboard

5. Summary and recommendations

This report gives a review of the existing standards and metrics for energy use in data centres. Data centre use is set to continue to grow and managing this growth in a way that minimises its environmental impact is a challenge for every government.

There are several possible pathways that could be considered by governments to track and manage the sustainability impact of data centres, based on international examples and using existing technology. There are also relevant further explorations that could help direct policy in this area. The following sections outline recommendations for actions and further investigations and then presents conclusions from the review.

5.1 Possible pathways for action by governments

It is evident from this research that there is no single policy approach that can address the sustainability impact of large and growing data centre use. The range of sizes, operational models and usage make it impossible for one policy to be effective for all data centre types.

There are examples of policies which have been adopted in different jurisdictions which can provide a starting point for consideration elsewhere, including both statutory and voluntary approaches. While any one policy could be effective, most policies will reinforce each other, meaning that the more policies that are adopted the greater impact each will have.

These policies for consideration are listed below.

1. Require all data centres operators to report or declare performance

Voluntary labels and certifications can be helpful but are likely to only be adopted by market leaders. A statutory mandatory requirement to report (i.e. in confidence within government) or declare (put in the public domain) performance could have several desirable effects, namely:

– Attracting greater management attention, increasing the likelihood of organisations not already engaged on this topic to make improvements

– Helping to identify the areas of highest impact and thereby to guide policy priorities

– Enabling governments to track progress and providing information for the monitoring and evaluation of any adopted policies

– Driving competition between providers (if declared)

The reported metrics need to be carefully chosen so that they provide useful information without being too onerous. It may be advisable to require more detailed information for larger data centres and also to gradually introduce the requirement so that smaller data centres have more time to prepare for compliance.[1]

The evidence from the US pilot to include data centres in their Commercial Buildings Energy Consumption Survey (described in Appendix 3. Energy performance data) suggests that active industry co-operation is essential to enable gathering this data.

The author has not found evidence that any Government has yet taken the step of requiring performance to be reported or declared. However the European Commission has proposed a revision to the Energy Efficiency Directive (EC 2021) whereby large data centres (with a power requirement of 1MW or greater) be required to make an annual disclosure of key sustainability information to the respective Member State, which would then be published. This has largely been supported by an EU industry body (DIGITALEUROPE, 2021). It is not clear whether this will be adopted and if so when it would take effect.

2. Adopt Minimum Energy Performance Standards for servers and data storage

Energy saved by greater IT efficiency can have a multiplier effect, reducing infrastructure energy use proportionately. Two jurisdictions, the EU and Japan, have set Minimum Energy Performance Standards (MEPS) for IT equipment. Many countries have similar legislative frameworks for setting MEPS; (for example Federal energy conservation standards in the US and the Greenhouse and Energy Minimum Standards (GEMS) Act in Australia). Countries could adopt similar regulations under these. Most of these countries also have energy ratings label[2] (for example Energy

1 Although smaller data centres may have the greatest gains to make in energy efficiency – see for example Ganeshalingham et al (2017)

2 A report by Energy Efficient Strategies (2014) describes the policies that were in place in 2013. CLASP provide an online database of these policies.

Guide in the US); the MEPS could be accompanied by rating labels to enable purchasers to be able to distinguish the best performing equipment and provide an incentive to manufacturers to sell high energy efficiency products.

3. Adopt a Minimum Energy Performance Standards for data centres

China has recently adopted a MEPS for data centres using PUE as the central metric.

There are two reasons for not following this example: one is that without good data on what current practice is (see one of the points in areas of further study below and the findings in Appendix 3. Energy performance data) it would be difficult to justify where to set the performance threshold. The second is that PUE is not a good measure for comparing energy or resource efficiency between data centres, that is, it is not a reflection of the overall energy, productivity or resource efficiency of a data centre.

Nevertheless now that China has set a precedent it may be worth considering adopting this approach as a short-term measure while more information on performance is gathered and published and more satisfactory metrics are developed.

4. Extend coverage of an existing industry energy efficiency programme to data centres

Some countries have an existing policy or programme to increase energy efficiency in industry; these may be voluntary or compulsory or a combination. They can include requirements to: undertake energy audits, adopt energy management systems, report energy use annually, and/or meet efficiency targets. They may include governments providing technical support and financial incentives. For instance, in Japan a compulsory requirement for energy efficiency action is combined with a voluntary benchmarking scheme.

Such schemes could be extended to include data centres (above a given energy-use threshold). One example of this type of policy is in the Netherlands–commercial data centres are one of the 19 sectors in the Energy Saving Obligation; which requires organisations to adopt energy saving measures (from an approved list, all of which have a payback period of 5 years or less).

5. Set building code requirements for HVAC equipment or mechanical loads and electrical losses

In some countries, such as Australia, Canada and the US, building codes or regulations are set regionally, at state or province level, so federal governments cannot act on these directly. However in these countries federal governments can consult with and provide support to other levels of governments and so have some effect on what is adopted.

Most data centres to date use ‘conventional’ cooling techniques, that is, a system that cools and circulates air. The efficiency of these systems can be improved cost-effectively by the use of economizers. Two possible approaches have been demonstrated in the US: the Californian building code requires economizers for new data centres;[3] while a performance-based approach to reducing mechanical loads and electrical losses set in ASHRAE 90.4, has been adopted in Washington State.

Alternatively, or in addition, governments could adopt or consult with other levels of government on adding a requirement that HVAC systems for data centres have to be inspected on a regular basis, (which is the case for large (>70kW) HVAC systems, irrespective of application, in the EU under the EPBD).

6. Provide good practice advice

Some good practice advice and resources have been produced specifically for national audiences, for example NABERS (2020) for Australia or the Lawrence Berkeley National Laboratory’s Center of Expertise for Energy Efficiency in Data Centers in the US.[4] If each country reviewed the material already available in their jurisdiction, updated, expanded, and then publicised it widely, this could be useful for data centre operators.

An alternative approach would be to provide a web page signposting information produced by or for others. Examples of good practice guidance found in the course of this study are Huang and Masanet (2017, USA), Acton et al (2021, the EU), ENERGY STAR (the US[5]) or produced by the Green Grid (Singh, 2011, international).

This could include advice and support on the purchase of renewable energy and low carbon backup power.

This advice may be presented as adding another, data centre, strand to an existing portfolio of energy advice

3 Some experts pointed out that economizers would not be suitable for all climates.

4 This includes Data Center Profiler (DC Pro) and the PUE Estimator – two “early stage” scoping tools designed for data centre owners and operators to diagnose how energy use is distributed in their data centre and determine ways to save energy and money.

5 ENERGY STAR data centers

for industry; however this strand would need to be highly visible and actively promoted to data centre owners and operators to be effective.

7. Provide incentives for good practice

One way to encourage the uptake of good practice is to provide incentives. This could be done by encouraging or requiring utilities to offer support through their energy efficiency programmes. EPA (2012) gives examples of these utility programmes in the USA which include:

- Training on energy efficiency
- Facility audits
- Engaging trade allies
- Offering incentives

National or regional (state or province) governments could also offer financial incentives to reward companies who increase energy efficiency. Two examples of this approach are included in this report. They both offer rebates on environmental charges on electricity: the CCA scheme in the UK, and the French rebate scheme, due to take effect in 2022.

8. Utilise public sector influence

In all the countries studied for this report the public sector owns considerable data centre capacity and makes widespread use of data centre services, via the cloud. The public sector can use their direct control of this resource to reduce its environmental impact use, incentivise suppliers to improve their performance and provide an exemplar for the private sector.

Four examples of this have been identified: the New South Wales government requirement for a minimum NABERS rating for data centres owned or leased by agencies (Resource Efficiency Policy); the US Federal Data Center Optimization Initiative, the EU Green Public Procurement guidelines and the Netherlands' Sustainable Public Procurement guidance for Networks, Telephone Services and Telephone Equipment. There may be existing mechanisms within the public sector of each country which could be adapted or amended to cover this.

9. Develop or adopt, and promote a voluntary good practice certification/label for data centres

Voluntary certification schemes/labels for energy best practice can help owners and operators to cut operational energy costs. They also provide an external validation of their good environmental performance–which could be of value for corporate reputation and in marketing services to users (for colos and cloud service providers).

Such schemes can be data centre specific, such as the EU Code of Conduct, or an adaptation of existing scheme; building related, such as BEAM Plus in Hong Kong or eco product/service related such as Blue Angel in Germany. Most of the examples for data centres found in the course of writing this report were country specific: for example, ENERGY STAR in the US or NABERS in Australia. But a number are international, such as the Data Centre Alliance Certification Scheme and LEED for data centres.

Governments have a number of options to consider if they want to adopt this type of policy tool. They can:

- Develop a data centre specific variation on an existing national certification/label (themselves or ask the lead organisation (generally an NGO or trade association))
- Develop a new data centre specific certificate/label (themselves or ask an NGO or trade association)
- Encourage data centre owners and operators to adopt an international certification/label (having first investigated their suitability)

New schemes should build from best practice of existing schemes – most of which publish their requirements.

In all cases development or 'adoption' of a scheme would need to follow a consultation with stakeholders, industry and beyond, to establish their appropriateness and viability.

Any new development would need to be promoted to the industry. There are costs[6] in achieving certification so all of these approaches would be more effective if they were supported by incentives (point 7) or could be used to meet a regulatory requirement (point 4).

5.2 Areas of further study

There are some topics of concern which were outside the scope of the current review but which could be valuable in the development of effective policy or identify additional environmental risks and how to address them. These are outlined in this section.

6 There may be a fee; it will also take company resources – staff time and possibly capital costs to meet the requirements.

A. Country specific measures

1. Gather information on current data centre performance nationally

As noted above and detailed in Appendix 3. Energy performance data data on data centre performance is very sparse and even fewer data are available at national level. A picture of performance would inform the need for and the development of the policy options listed above.

One option could be to gather data from electricity network operators and publish aggregated data, following the example of Statistics Netherlands,[7] and, to a more limited extent, Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia (Lindsay et al 2021). This could give an indication of the size and regional distribution of the energy demand and how it is changing over time. This would require suitable way of handling the data to respect operators' privacy and a suitable agent to undertake the analysis.

Undertaking an industry wide survey, perhaps in co-operation with the national trade association may yield more comprehensive information, although as noted above, the experience in the US trialling extending the Commercial Buildings Energy Consumption Survey suggest that this would not be a trivial exercise.

A separate survey of publicly owned and operated centres could also be enlightening, as the EU EURECA project (reported in Bashroush and Lawrence 2020) found that there was significant room for improvement in this sector.

This data could be augmented by a market analysis giving an indication of the distribution of the market and projections for the areas (geographic and technical) of growth in the sector.

B. Topics suitable for international engagement and collaboration

Data centres operate to some extent in an international market and the challenges and issues of reducing their environmental impact are largely independent of where they are located. That being the case there is much to be gained by multinational cooperation; governments can pool their resources for greater impact.

This could be via existing international fora for collaboration on energy efficiency of appliances and equipment, which include SEAD (Super-Efficient Equipment and Appliance Deployment – an initiative of the Clean Energy Ministerial) and the IEA Energy Efficiency End-use Equipment (4E) Technology Collaboration Programme (TCP). There are other IEA TCPs, (including the Buildings and Communities TCP that BECWG are part of), which may be suitable. There are also regional multi-national fora, such as the APEC (Asia Pacific Economic Cooperation) Expert Group on Energy Efficiency and Conservation. Alternatively it might be preferable to create a forum specifically focused on data centres.

However it is done the author suggests the following topics as requiring further study which could be done by national governments but would benefit from collaboration:

1. Engage with industry on effective metrics

Industry and regulators lack a set of robust indicators for the performance of data centres. Despite many alternative metrics being proposed by industry groups and academics none have been widely adopted. The lack of effective metrics has been a barrier to effective regulatory and voluntary action on data centres.

Wu et al (2019) point out that the ease of reporting and comparing large amounts of data electronically also means that there is no real need to reduce energy efficiency behaviour to a single figure. However, there does need to be a standardised reporting format so that data are easily comparable. They suggest that Governments use their extensive experience engaging industry on developing test standards and metrics to address this issue. There may need to be different metrics for different applications.

An expert noted that there is work ongoing in the EU to develop metrics for a data centre's overall environmental and digital performance. This is being undertaken by the European Commission (EC) in consultation with various bodies such as the Climate Neutral Data Centre Pact, the Sustainable Digital Infrastructure Alliance and others. It may be worth co-ordinating with the EC on this work.

Under the 2020 Energy Act the US Department of Energy was tasked with "in collaboration with key stakeholders, shall actively participate in efforts to harmonize global specifications and metrics for data center energy and water efficiency…(including a) facilitating " development of an efficiency metric that measures the energy efficiency of a data center (including equipment and facilities)" (Hoffman et al 2021). The author has not found reports on how this requirement is being met.

7 Statistics Netherlands, Netherlands Electricity supplied to data centres, 2017–2019, 16th April 2021 – described in Appendix 3. Energy performance data

Another, international, project on metrics for data centre efficiency was announced in August 2021. This is a new Task undertaken under the IEA 4E TCP Electronic Devices & Networks Annex (EDNA). The work is expected to report in early 2022. This may resolve the issue but further work is likely to be required, if only to formalise the findings and encourage uptake.

2. Undertake research on data centre use of potable water and ways to reduce it

Data centre water use is increasingly being reported as an issue, by operators, consultants and in the specialist press.[8] As noted by Mytton (2021) awareness of water use and the means to reduce it is lagging years behind that for energy, and it has received much less attention to date (for example only 51% of respondents to Uptime Institute's 2021 survey (Bizo et al 2021) compile and report water usage for corporate sustainability for data, whereas 82% collect data on IT or data centre power consumption). There is an overlap between energy and water use and some of the best practice guidance identified in this report includes water use. However, research specifically on water use and the interrelationship between energy and water use is needed[9] to identify best practice and possible policy options to encourage this.

3. Undertake research on the challenges from edge computing and how to address them

Edge data centres, the use of data centres close to the point of use, is expected to grow. Micro data centres, at the 'local edge', represent a departure from the current norm in terms of scale and the requirement for robustness. Existing regulatory and permitting regimes and operational best practices are designed for dedicated facilities in buildings. It is not clear how these can be adapted to effectively cover data centres that operate, for example, in containers in car parks or on roofs. If the more bullish projections for the market for edge data centres are correct it will become a matter of urgency to find ways to address this or data centre energy use could increase rapidly.

5.3 Conclusions

The evidence suggests that data centre capacity growth is set to continue for the foreseeable future. Indeed, the pace of change may even accelerate, due to the growth in edge computing. The services that data centres provide look to become more embedded in daily life, both personal and business. Increasing digitalisation offers opportunities for energy savings across many applications, as noted by, for example, the IEA.[10]

There is a wide range of performance in the industry, in particular a gulf between the hyperscale and small server rooms. The former have reduced their energy use by developing and applying best practices and their greenhouse gas emissions by purchasing their electricity from renewable sources. This is likely in response to two factors: energy costs form a high proportion of their operational costs and their sensitivity to concern about their environmental impact, within governments and society at large.

The need for government action, whether voluntary or regulatory, is more apparent at the medium or small scale, where energy use is less visible and expertise is not so readily available. No single policy tool is likely to address these applications; a variety will be needed to support positive changes. Several have been developed and applied in different countries; other governments could consider adopting one or all of these.

Energy use for conventional data centres has been studied and efficiencies developed for well over a decade. This review has identified two challenges which have had less consideration but which now look to justify attention from policy makers and the industry:

Data centre water use can be extensive. This has not impacted on operational costs or raised the same level of environmental concern as energy use and relatively little attention has been paid to it. However, in a world where water resources are under increasing pressure, not least because of the effect of climate change (see for example UN 2019), this needs to be addressed.

The requirement for data processing and storage near the point of use – edge computing–is a new development but is likely to become a major feature of data centres in future. Their different nature from conventional data centres means that finding ways to minimise their environmental impact presents new challenges.

The growth in data centre capacity does not need to be matched by a proportional growth in energy demand. The evidence found in the course of this review is that there are the means to reduce energy use using known technology and practices. It will take continuing attentiveness and action by governments and industry to make this so.

8 For example this article on the Dutch Data Center Association web site, April 2021, Sustainable water supply for Google's data center in Eemshaven.

9 One exception is an examination of data centre carbon emissions and water use for some data centres in the US, Siddik et al, 2021

10 IEA Article, June 2019, Energy efficiency and digitalisation.

Appendix 1. Standards listing

Related to security, availability and resilience

Table 9 lists the relevant measurement standards related to security, availability and resilience as identified in this research. All of these standards are operational

Table 9. Security, availability and resilience related measurement standards

Number	Name	Coverage
EN 50600-1	Data centre facilities and infrastructures. General concepts	General concepts. Specifies a classification system, based upon the key criteria of "availability", "security" and "energy efficiency"
EN 50600-2-1	Data centre facilities and infrastructures	Building construction (risk analysis and availability)
EN 50600 2-2	Data centre facilities and infrastructures	Power supply and distribution (availability classification)
EN 50600-2-3	Data centre facilities and infrastructures	Environmental control (availability classification)
EN 50600-2-4	Data centre facilities and infrastructures	Telecommunications cabling infrastructure (availability classification)
EN 50600-2-5	Data centre facilities and infrastructures	Security systems (risk analysis and availability)`
EN 50600-2-10	Data centre facilities and infrastructures	Earthquake risk and impact analysis
EN 50500-3-1	Data centre facilities and infrastructures	Management and operational information
ISO/IEC TS 22237-1	Data Center Facilities and Infrastructures	General concepts. Currently a direct copy of EN 50600-1
ISO/IEC TS 22237-2	Data Center Facilities and Infrastructures	Building construction (risk analysis and availability) Currently a direct copy of EN 50600-2-1
ISO/IEC TS 22237-3	Data Center Facilities and Infrastructures	Power supply and distribution (availability classification) Currently a direct copy of EN 50600-2-2
ISO/IEC TS 22237-4	Data Center Facilities and Infrastructures	Environmental control (availability classification) Currently a direct copy of EN 50600-2-3
ISO/IEC TS 22237-5	Data Center Facilities and Infrastructures	Telecommunications cabling infrastructure (availability classification) Currently a direct copy of EN 50600-2-4
ISO/IEC TS 22237-6	Data Center Facilities and Infrastructures	Security systems (risk analysis and availability)` Currently a direct copy of EN 50600-2-5
ISO/IEC TS 22237-7	Data Center Facilities and Infrastructures	Management and operational information. Currently a direct copy of EN 50600-3-1
ANSI/BICSI 002-2019	Data Center Design and Implementation Best Practices	Availability class, reliability class, telecommunication class, network class, system class

Related to Key Performance Indicators and best practice

Table 10 lists the relevant measurement standards related to key performance indicators and best practice identified in this research.

Test standards in italics are in preparation. All other standards are operational.

Table 10. Key performance indicator and best practice standards

Number	Name	Coverage
ISO/IEC 30134		
Part 1–	Data centres – Key Performance indicators	Overview and general requirements
Part 2	Data centres – Key Performance indicators	Power usage effectiveness (PUE)
Part 3	Data centres – Key Performance indicators	Renewable energy factor (REF)
Part 4	Data centres – Key Performance indicators	IT equipment energy efficiency for servers (ITEE)
Part 5	Data centres – Key Performance indicators	IT equipment utilization for servers (ITEU_SV)
Part 6	*Data centres – Key Performance indicators*	*Energy Reuse Factor (ERF)*
Part 7	*Data centres – Key Performance indicators*	*Cooling Efficiency Ratio (CER)*
Part 8	*Data centres – Key Performance indicators*	*Carbon Usage Effectiveness (CUE)*
Part 9	*Data centres – Key Performance indicators*	*Water Usage Effectiveness (WUE)*
EN 50600 4:	Data centres – Key Performance indicators	
Part 1–	Data centres – Key Performance indicators	Overview and general requirements
Part 2	Data centres – Key Performance indicators	Power usage effectiveness (PUE)
Part 3	Data centres – Key Performance indicators	Renewable energy factor (REF)
Part 4	Data centres – Key Performance indicators	IT equipment energy efficiency for servers (ITEE)
Part 5	Data centres – Key Performance indicators	IT equipment utilization for servers (ITEU_SV)
Part 6	Data centres – Key Performance indicators	Energy Reuse Factor (ERF)
Part 7	Data centres – Key Performance indicators	Cooling Efficiency Ratio (ERF)
Part 8	Data centres – Key Performance indicators	Carbon Usage Effectiveness (CUE)
Part 9	Data centres – Key Performance indicators	Water Usage Effectiveness (WUE)
ISO/IEC DTR 30133.3	*Information technology — Data centres — Guidelines for resource efficient data centres*	
EN 50600-5-1	*Data Centre Maturity Model*	
CSA C510:21	Ideal state benchmarking and application of benchmark energy factor for data centres	Benchmark Energy Factor (BEF)
PD/CLC TR 50600-99-1	Data centre facilities and infrastructures	Technical Report. Recommended practices for energy management aligned with the contents of EU CoC BP V.11.1.0
PD/CLC TR 50600-99-2	Data centre facilities and infrastructures	Technical Report–Recommended practices for environmental sustainability

Table 10 Continued

Number	Name	Coverage
PD/CLC/TR 50600-99-3	Data centre facilities and infrastructures	Technical Report- Guidance to the application of EN 50600 series
ISO/IEC TR 21897	*Information Technology–Data centres*	*Methods and tools to assess and express energy production, storage and consumption at data centre level in reference to primary energy*
ISO/IEC TR 30132-1:2016	Information technology sustainability — Energy efficient computing models —	Part 1: Guidelines for energy effectiveness evaluation
ISO/IEC 19395:2015	Sustainability for and by information technology	Smart data center resource monitoring and control
ASHRAE 90.4-2019	Energy Standard for Data Centers	Energy use for data centres. Sets required values as well as metrics
ASHRAE TC 9.9 2021	Thermal Guidelines for Data Processing Environments, 5th Edition	Sets range of temperature and humidity conditions which classes of equipment can operate in.
ETSI EN 300 019–1-3	Environmental conditions and environmental tests for telecommunications equipment; Part 1–3: Classification of environmental conditions	Sets range of temperature and humidity conditions which classes of equipment can operate in
ETSI EN 305 200-2-1	Energy management; Operational infrastructures; Global KPIs Part 2: Specific requirements	Sub-part 1: ICT sites
ETSI EN 305 200-3-1	Energy management; Operational infrastructures; Global KPIs; Part 3: ICT sites	Sub-part 1: DCEM (Data processing and Communications Energy Management)
ISO/IEC TR 20913	Information technology — Data centres	Guidelines on holistic investigation methodology for data centre key performance indicators
ETSI EN 105 174-2	Access, Terminals, Transmission and Multiplexing (ATTM); Broadband Deployment and Energy Management; Part 2: ICT sites (equivalent to TR 50600-99-1)	Recommended practices for energy management
ETSI TS 105 200-3-1	Energy management; Operational infrastructures; Implementation of Global KPIs;	Part 3: ICT Sites; Sub-part 1: DCEM (Data processing and Communications Energy Management)
ETSI EN 305 174-2	Access, Terminals, Transmission and Multiplexing (ATTM); Broadband Deployment and Lifecycle Resource Management; Part 2: ICT Sites	Lifecycle Resource Management;
BICSI 009 2019	Data Center Operations and Maintenance Best Practices	O&M best practice
NA	Data Center Maturity Model, The Green Grid ref 171	A model which provides goals and direction for improving energy efficiency and sustainability across all aspects of the data centre. It defines six levels of maturity from level 0, minimal account of sustainability, to level 5, visionary, with the aspiration that a data centre could move through these in 5 years. It is explicitly intended for an enterprise to compare its own data centres over time, not to compare facilities from different organizations.

Table 10 Continued

Number	Name	Coverage
ITU-T L.1300	Best practices for green data centres	Broad operational best practice including IT energy efficiency and cooling practices
ITU-T L.1304	Procurement criteria for sustainable data centres	Guideline on green procurement for data centre
ITU-T L.1305	Data centre infrastructure management system based on big data and artificial intelligence technology	Application of AI to data centre DCIM for improve cooling and management improving efficiency

Certification of resilience and redundancy

Data centre availability, as agreed in the Service Level Agreement (SLA) is of paramount importance for customers and therefore for operators. In considering any changes to a data centre facility or operation, availability is preeminent above any other consideration including cost or sustainability.

Availability is not directly related to energy efficiency or environmental impact, but it has to be considered as maintaining high availability may increase environmental impact (for example by the use of diesel generators as backup power supplies).

Availability cannot be guaranteed directly so certifications quantify how and when maintenance and upgrades can be undertaken, and the degree of protection against disruption from different sources. Increasing resilience against incidents and redundancy of equipment is likely to increase availability but will also increase the capital and operating costs so operators and/or users have to match the appropriate level against their requirements and not over specify. Levels of availability and resiliency are classified in EN 50600-1 and ISO/IEC TS 22237.

There is a longstanding (over 25 years) international commercial certification system operated by Uptime Institute. This has four tiers[1] from Tier 1, with basic capacity to the highest, Tier IV, which has several independent and physically isolated systems that act as redundant capacity components and distribution paths.

Japan's Data Center Facility Standard (Japan Data Center Council, 2011) is only designed for Japan. It appears to be similar to Uptime's classification, modified to account for the very high grid reliability in Japan and increased attention paid to earthquake risk.

Eco[2] operate the Data Centre Star Audit scheme (Eco 2013), another international commercial certification system which assesses the quality of a data centre.

1 For more information
2 Eco – the association of the internet industry

Relating to servers, other components and HVAC

Table 11 lists the standards relating to servers, other components and HVAC identified in the course of this research.

All of these standards are operational.

Table 11. Standards relating to servers, other components and HVAC

Number	Name	Coverage
ASHRAE 127-2020	Method of Testing for Rating Air-Conditioning Units Serving Data Center (DC) and Other Information Technology Equipment (ITE) Spaces	Air conditioning for IT spaces
ISO 16890-1	Air filters for general ventilation — Part 1: Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM)	Air quality
ISO 14644-8	Cleanrooms and associated controlled environments — Part 8: Classification of air cleanliness by chemical concentration (ACC)	Air quality The ASHRAE white paper '2011 Gaseous and Particulate Contamination Guidelines for Data Centers' recommends that data centre air quality is monitored and cleaned according to ISO 14644-8 Class 8. [peripheral]
IEC 62040-5	Uninterruptible power systems (UPS)–Part 5-3: DC output UPS–Performance and test requirements	Uninterruptible power systems/supplies
ISO/IEC TR 23050	Data centers — Impact on data center resource metrics of electrical energy storage and export –	Excess Electrical Energy Factor (XEEF) KPI to quantify the electrical energy provided back from data centre to the utility
ETSI–EN 303 470	Energy Efficiency measurement methodology and metrics for servers	a metric using the Server Efficiency Rating Tool (SERT™), test conditions and product family configuration for the assessment of energy efficiency of computer servers using reliable, accurate and reproducible measurement methods. Equivalent to ISO/IEC 30134-4
ETSI EN 300 019-1	Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment	Sets classes of environmental conditions for communications equipment which can be applied to servers.
ISO/IEC 21836:2020	Information technology — Data centres — Server energy effectiveness metric	Specifies a measurement method to assess and report the energy effectiveness of a computer server
ISO/IEC 30134-4	Information technology — Data centres — Key performance indicators — Part 4: IT Equipment Energy Efficiency for servers	Defines a server energy efficiency metric

Appendix 2. Advantages and disadvantages of PUE

van de Voort et al's (2017a) literature review of PUE gives an overview of its merits and disadvantages. These are given below, expanded with commentary from other sources.

PUE Merits

The total efficiency of a data centre comes down to how much useful work is produced per unit of energy. But as different data centres perform different tasks which vary in time, useful work is difficult to determine. Therefore, PUE gained popularity as it shows the efficiency not by quantifying useful work, but by showing the ratio of energy available for useful work and the part that is lost to overhead, also referred to as the infrastructure component. As energy consumption is one of the major data centre expenses the requirement to reduce their infrastructure energy consumption is one that all data centres have in common, despite their different specialisations. This is what led to the industry wide adoption of PUE as the main performance metric soon after its introduction. It has been successful at focusing attention on infrastructure energy use and reducing this.

Uptime Institute's 2020 survey (Ascierto et al 2020a) shows the global average PUE decreased from 2.5 when it was first introduced in 2007 to 1.59 in 2020. The greatest reductions in PUE took place between 2007 and 2013 (PUE 1.65) with only small improvements since then. While these data are selective and therefore do not reflect the market as a whole they give some indication of the situation.

As ISO/IEC 30134-2 (2016) states "When viewed in the proper context, PUE provides effective guidance and useful insight into the design of efficient power and cooling architectures, the deployment of equipment within those architectures, and the operation of that equipment". As such:

> PUE provides a means to determine:
>
> – opportunities for the improvement of the operational efficiency of a data centre,
>
> – the improvement of the designs and processes of a data centre over time, and
>
> – a design target or goal for new data centres across the anticipated IT load range.

PUE disadvantages

PUE is not a reflection of the overall energy, productivity or resource efficiency of data centre. In another review Horner and Azevedo (2016) state "PUE is a reasonable and useful metric for assessing the infrastructure efficiency of a data center. The issue is that PUE is far from a comprehensive metric, and quoting PUE values and nothing else stops short of providing a truly meaningful sense of data center performance."

van de Voort et al (2017a) point out that "as the computational power per watt increases per Moore's law the useful work produced per watt can double every two years, therefore renewing IT equipment might be one of the best energy efficiency strategies", reducing energy use and energy bills. As IT energy use is the denominator in the PUE equation; while energy use decreases the PUE increases. So in the worst case using PUE as a performance metric could provide a perverse incentive against this strategy of IT replacement.

Separate to this is that using PUE as a metric concentrates attention too strongly on infrastructure energy use. Bashroush et al (2020) state that "Major energy efficiency opportunities involving IT remain untapped — partly due to a misplaced management focus on infrastructure." And that "Energy-saving opportunities on the IT side are so great that if fully addressed, they would significantly reduce data center energy use and carbon footprint, would slash energy bills and would likely lead to reduced demand for cooling and critical power equipment." Further increasing IT efficiency reduces the heat load and therefore, all else being equal, the infrastructure use, providing additional energy savings.

Further PUE also does not take into account the:

– IT load utilisation or productivity,

– efficiency of on-site electricity generation,

– efficiency of other resources such as human resource, space or water, and

– use of renewable energy resources or accounts for re-use of waste by-products (such as heat).

Other metrics have been developed which account for most of these factors individually and they have been used to complement PUE. However, all of them have more narrow coverage so none of them can directly replace PUE. Finding a metric for IT productivity that is robust and practicable has proved difficult and is still unsolved.

Appendix 3. Energy performance data

Australia

The report to the E3 Program by Consumer Research Associates (2014) estimated number of servers, projected energy use and split of energy use by sector.

A more recent source on the Australian market (Tempest 2020) stated that over 50,000 Data Centres were registered in Australia and 'energy is the largest single cost with an average 20% operational cost in any Data Centre'.

CSIRO (Lindsay et al 2021) reviewed the drivers behind the growth in capacity and energy use of data centres in Australia and searched for data on current energy use. The latter included some aggregated data on energy use from the Australian Energy Market Operator (AEMO) which they had access to under an existing program, the National Energy Analytics Research (NEAR) Program. They concluded that "Publicly available data also poorly serves the Australian context" and recommended that "AEMO data should be leveraged to answer specific questions about the current state of the sector and its recent trajectory". They also suggested that an industry forum would be useful to increase discussion and share information between data centre operators, energy network businesses, the energy market operator, government policy teams and the research community.

China

Greenpeace have published several reviews of energy use in China's tech industry, most recently in 2021, the detailed report in Chinese (Greenpeace 2021) with a summary in English (Greenpeace 2021a). The analysis focuses on China's 22 largest cloud and data centre companies, which they say comprises 74% of China's IaaS[1] public cloud market and over 78% of China's data centre market. Companies were rated using four criteria, one of which was Energy Efficiency and Carbon Reduction, which included four sub-criteria, one of which was energy efficiency performance. One piece of data extracted from the full report (in Chinese, figure 3 page 12) is that for the 224 data centres covered by the review: 2% had a PUE of < 1.2; 37% had a PUE between 1.2 and 1.4; 54% had a PUE between 1.4 and 1.6 and 7% had a PUE greater than 1.6. It is possible that more detailed data could be extracted from this report if it was felt to be of interest.

The Greenpeace report references a report by the Chinese Institute of Electronics (2020), also in Chinese. It is possible that this report has additional data on energy use which could be extracted from this report if it was felt to be of interest.

Europe

Data for signatories to the European CoC to 2016 are reported in Avgerinou et al, 2017 and discussed in the Evidence on the effectiveness of metrics, policies and certifications and market changes section above. Figure 5 shows the performance by year. In 2016 the average PUE was 1.64 with the maximum 2.7 and minimum of 1.1 (read from the graph).

International

Greenpeace has published several 'editions' of their "Clicking green" report which ranks the environmental performance of internet related companies (including colocation companies but also others such as social media and e-commerce companies) most recently in 2017 (Greenpeace 2017). Some data are presented on PUE but by company rather than by individual data centre or region.

The Uptime Institute survey (Ascierto et al 2020a) gives an indication of the average PUE reported by survey respondents. It shows the global average PUE decreased from 2.5 when it was first introduced in 2007 to 1.59 in 2020. The greatest reductions in PUE took place between 2007 and 2013 (PUE 1.65) with only small improvements since then.

The Netherlands

Amsterdam is one of the four major data centre market hubs in Europe (known by the four cities which dominate the market, FLAP, Frankfurt, London, Amsterdam, Paris, CBRE 2021b). The Dutch Data Center Association, DDA, publishes an annual report which gives a detailed description of the data centres owned and operated by its members (DDA 2020) in Dutch. This states that "the PUE of Dutch DDA data centres fluctuates between 1.15–1.3".

Statistics Netherlands has published data on the electricity supplied to data centres for 2017-2019[2] based on data provided by network operators. They found that:

1 Internet as a Service

2 Statistics Netherlands, Netherlands Electricity supplied to data centres, 2017–2019, 16th April 2021

– 1.6TWh was supplied in 2017, increasing to 2.7TWh in 2019

– In 2019 2.7% of electricity in the Netherlands was supplied to data centres

– Most of the electricity was supplied to large data centres (with a supply exceeding 7.5 GWh): 84% of electricity in 2017, 90% in 2019.

USA

NRDC (Whitney and Delforge 2014) reported the results of a survey conducted by Digital Realty Trust in January 2013 which indicated that only 20 percent of the 300 North American data centre companies with revenues of at least $1 billion and/or more than 5,000 employees had a PUE below 2.0, with the average at 2.9.

In the process of setting up the ENERGY STAR for data centres rating system the US EPA analysed the building energy and operating characteristics of 61 stand-alone US data centres (ENERGY STAR Portfolio Manager, 2018). (NB This is a small sample – in 2014 the NRDC estimated that there were 3 million data centres in the US[3] (Whitney and Delforge 2014)). The mean PUE of this sample was 1.924 with the maximum and minimum of 3.598 and 1.362 respectively.

The Energy Information Administration (EIA) 2018 data centre pilot (Energy Information Administration 2021) chose a sample size of 50 data centres in considering the costs and accuracy of the survey (20 private data centres and 30 colocation data centres). The surveys were undertaken by a surveyor visiting the building. The question they asked respondents about each data centre included:

– The square footage

– The number of workers

– The number of servers (numeric)

– The number of servers (numeric or categorical)

– The power usage effectiveness

They found that:

– The pilot response rate was 26%, less than half that of the main sample.

– The pilot cases required two times more contacts per completed case compared with the main sample.

– Item nonresponse was very high for items that are important to data centres (those listed above).

They concluded that data centre estimates were likely not feasible with current methods. EIA would need a quality frame[4] and cooperation from the industry in order to consider adding data centres as a separate building type to the Commercial Buildings Energy Consumption Survey.

3 One expert queried this number, they felt that three thousand servers was more likely. In any case the ENERGY STAR sample would seem to be relatively small.

4 Source of data with company names and addresses

Appendix 4. Edge data centres

Applications requiring edge data centres

Vertiv[1] (Pope A 2021) use four archetypes to classify edge uses:

1. **Data Intensive:** This includes uses where the amount of data makes it impractical to transfer over the network directly to the cloud or from the cloud to point-of-use due to data volume, cost, or bandwidth issues. Examples include smart cities, smart factories, smart homes/buildings, high-definition content distribution, high-performance computing, restricted connectivity, virtual reality, and oil and gas digitization.
2. **Human-Latency Sensitive:** This includes uses where services are optimized for human consumption, and speed is paramount. Delayed data delivery negatively impacts a user's technology experience, potentially reducing a retailer's sales and profitability. Use cases include smart retail, augmented reality, website optimization, and natural language processing.
3. **Machine-to-Machine Latency Sensitive:** This includes high speed cases which includes the arbitrage market, smart grid, smart security, and real-time analytics.
4. **Life Critical:** This encompasses uses that directly impact human health and safety. Consequently, low latency and reliability are vital. Use cases include smart transportation, digital health, connected/ autonomous cars, autonomous robots, and drones.

OpenNebula (2021) lists some estimated latency requirements in milliseconds for various types of applications, as shown in Table 12.

Table 12. Estimates of latency requirements for a selection of applications from OpenNebula 2021

Application	Estimated latency requirements in milliseconds
Industry 4.0[a], collaborative robots, remote surgery	<2
VR gaming, real time holograms	<5
Autonomous car, AR	<10
Cloud gaming	<20

a Also known as the Industrial Internet of Things (IIoT)

Characteristics of edge data centres

STL (2020) describe three operational models of edge data centres:

1. third parties (specialist)
2. telcos (telephone companies)
3. hyperscalers and telcos partnerships

All of these models are operating at present and seem likely to continue.

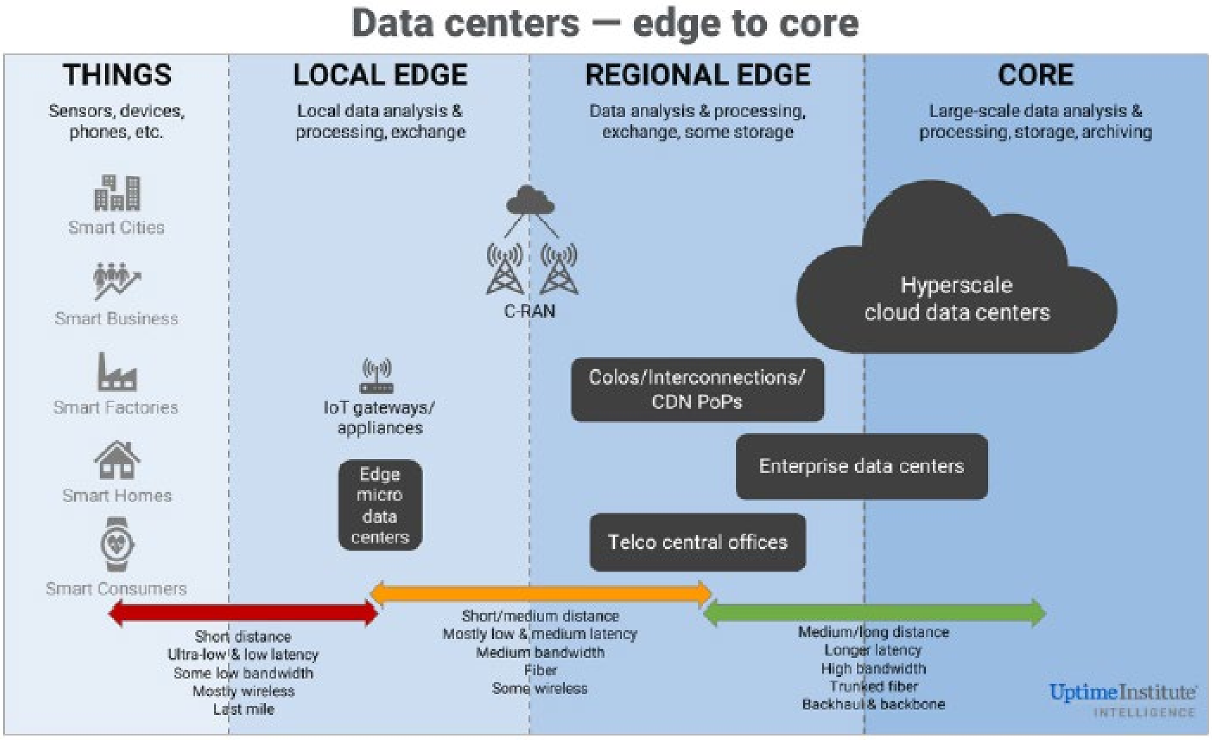
Ascierto and Lawrence (2020b) make it clear that 'edge computing' supplies many different applications with different requirements. They present an edge to core schema of data centres as reproduced in Figure 6

ASHRAE (2020) describe the environmental and reliability challenges of small edge data centres as including: large temperature and humidity fluctuations, air pollution, and dust. These concerns are for small, stand alone data centres such as:

- Modular data centres fabricated from steel shipping containers
- Prefabricated edge pods
- Small stand-alone brick-and-mortar data centres

1 Who provide data centre products and services

Figure 6. Uptime Institute's Data centers edge- to-core schema, from Ascierto and Lawrence 2020b



– Phone-booth-sized enclosures that hold a single rack

– Very small enclosures that hold only one or two servers

which may be mounted outdoors, such as on the rooftops of commercial buildings or in parking lots, or may be in semi-controlled location such as a warehouse. They are also likely to be less energy efficient than large data centres. There are no IT staff on site and this may present maintenance and management challenges.

Linux Foundation (2021) state that there is a new recognition that the high levels of redundancy common in large-scale facilities is both cost- and space-prohibitive in edge environments. Instead, edge data centres are beginning to rely on real-time monitoring and software-based failover to maintain reliability.

Current and future markets for edge computing

The Linux Foundation have made recent estimates of the edge computing market, conservative and aggressive cases, expressed as the rated power capacity of edge servers (Linux Foundation 2021). The conservative forecast has the global aggregate IT power footprint increasing from 1,078 MW in 2019 with a CAGR (Compound Annual Growth Rate) of 40% to reach 40,380 MW by 2028. The aggressive forecast results in a 70 percent CAGR to reach 120,840 MW by 2028.

These estimates seem high when compared with ballpark estimates of current capacity in 'conventional' data centres; the 2019 value would suggest that the former are around an additional 10%. The aggressive forecast for 2028 would be between four and five times the current conventional capacity, with a substantial potential impact on global data centre energy use. Fulton (2020) reports some experts questioning Linux Foundations' equivalent 2020 estimate of 102GW for the total edge footprint, which one expert estimated would translate to 893TWh energy use. McCarthy (2020) predicted a CAGR of 13% in spending on edge compute and storage between 2018 and 2023, much lower than the Linux Foundation's 'conservative' estimate. Villars and Goodison (2021) think that by 2023 half of new IT infrastructure will be being deployed in edge locations not in data centres. They state that while there are currently approximately 39,000 core data centres globally, the need will be at 7 million-plus edge locations such as factories, hospitals, airports, stores, hotels and construction sites.

While the overall scale of edge computing seems to be open for debate it is still interesting to note that Linux Foundation are predicting a different geographic split of the edge capacity to the 'conventional' in 2028, as shown in Table 13.

Table 13. Predicted geographic distribution of edge computing capacity in 2028 from Linux Foundation 2021

Region	Predicted % of edge computing capacity in 2028	Main areas of activity
Asia Pacific	37.7%	China, Japan and South Korea
Europe	29.0%	over half in Western Europe
North America	20.5%	
Latin America	7.0%	Brazil and Mexico
Middle East and Africa	5.8%	

Appendix 5. Market data and projections by region

China

Greenpeace (2019) predicts rapidly increasing electricity use in the data centre industry, as shown in Table 14. The report also predicted growth rates of electricity consumption by data centre by region over the period of 2018 to 2023 of between 10% (for Bejing – restricted by PUE requirements) to Hebei (141%).

In 2020 the Chinese Institute of Electronics (2020) predicted that energy consumption in 2030 would be double that of 2019, reaching around 1.5% to 2% of Chinese total electricity consumption.

Europe

Hintemann and Hinterholzer (2020) have made projections of energy use from 2020, as shown in Figure 7. The three scenarios have a considerable range in 2030.

International

Hintemann and Hinterholzer (2019) found a wide range of projections for data centre and server internet use to 2020 as shown in Figure 8 (it is assumed that a billion kWh is a TWh) ranging from keeping energy consumption constant to an increase by a factor of 40. They note that In the "best case" the energy consumption of data centres can remain largely constant. If Moore's Law[1] ends and the capacity of data centres increases significantly, annual energy consumption may increase to almost 3,000 TWh/a (Andrae/Edler 2015 "expected"). Andrae 2019 and Belkhir/Elmeligi expect an energy consumption of approx. 2000 TWh/a for 2030. If the current developments determined by Borderstep (the paper authors) continue, the energy consumption of data centres will double by 2030 compared to 2019 (from 400 to 800TWh). The range reflects the range of assumptions underlying them: growth in data traffic and increases in energy efficiency – do they continue on current trends (although these are also disputed), increase or decrease?

Note that, the 'best case' energy use matches the estimate as mentioned above, Masanet et al's (2020) for 2018.

There is evidence that Moore's Law may be slowing or coming to an end. Bashroush and Lawrence (2020) report data which shows server performance per watt plateauing, and power consumption at idle increasing (after a long period of decline), reproduced in Figure 9.

Table 14. Electricity Consumption of China's Data Centre Industry (2018–2023) from Greenpeace East Asia and the North China Electric Power University (2019)

Year	2018	2019	2020	2021	2022	2023
Electricity consumption in TWh	160.9	178.0	197.0	217.9	241.1	266.8

1 Moore's law is the observation that the number of transistors in a dense integrated circuit (IC) doubles about every one and a half years. This has appeared to result in an approximate doubling of energy efficiency over the same period, Koomey et al (2011), a trend which is also referred to Moore's Law or sometimes as Koomey's Law.

Figure 7. Energy Consumption of Data Centres in Europe to the Year 2030 in 3 Scenarios. From Hintemann and Hinterholzer (2020)

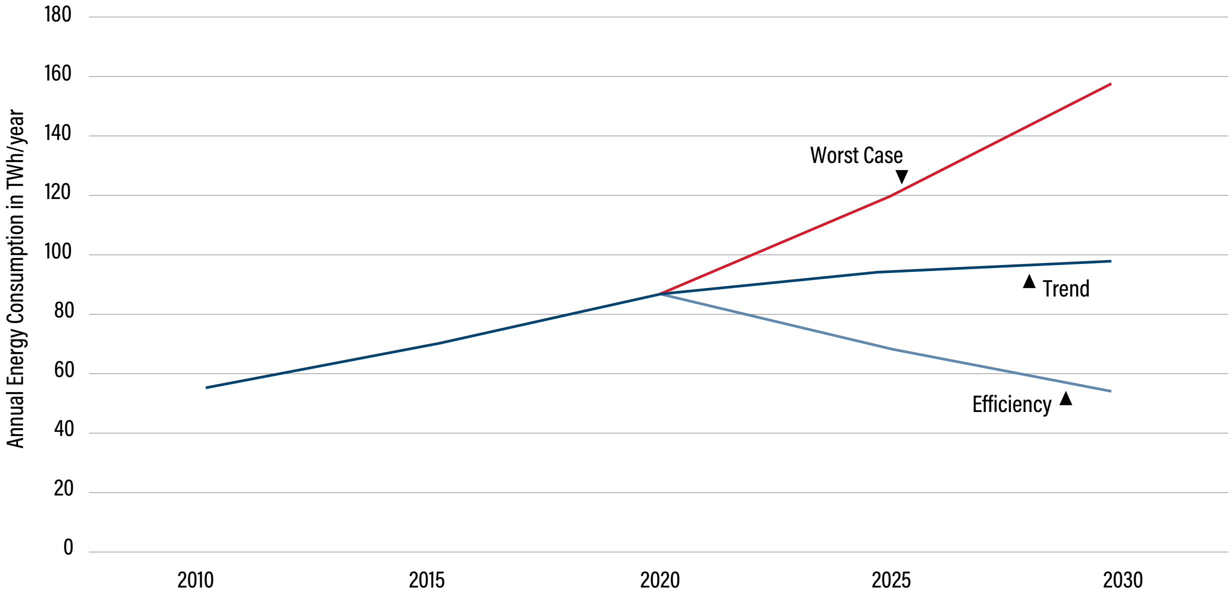


Figure 8. Ranges of projections for energy consumption of servers and data centres worldwide – forecasts to 2030 from Hintemann and Hinterholzer 2019

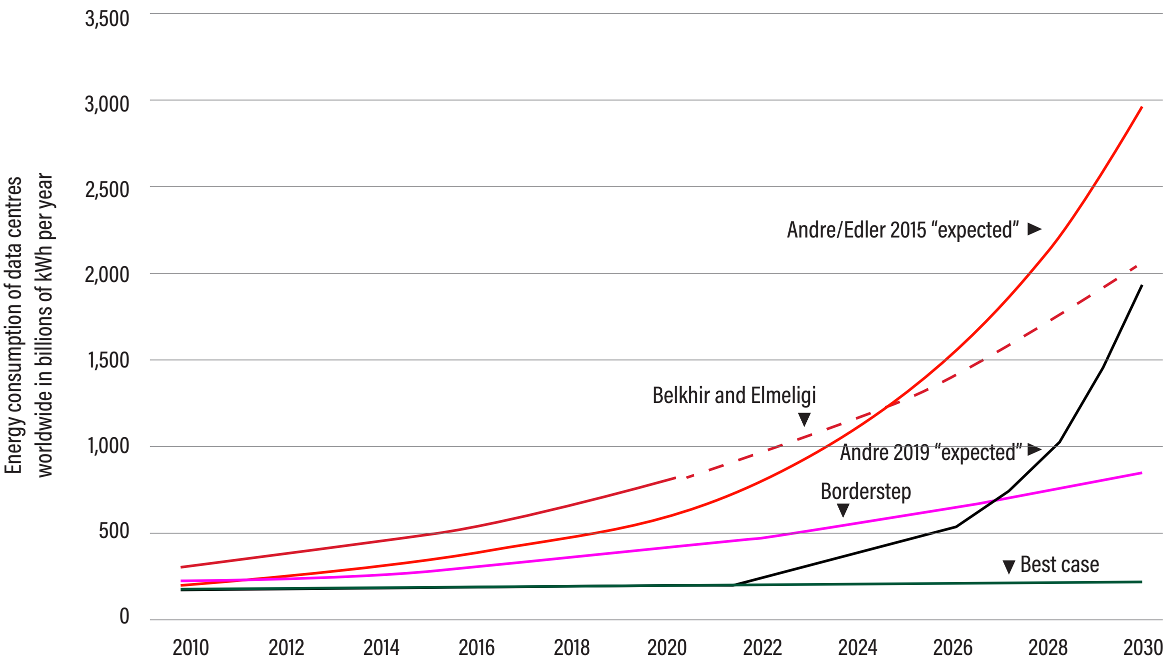
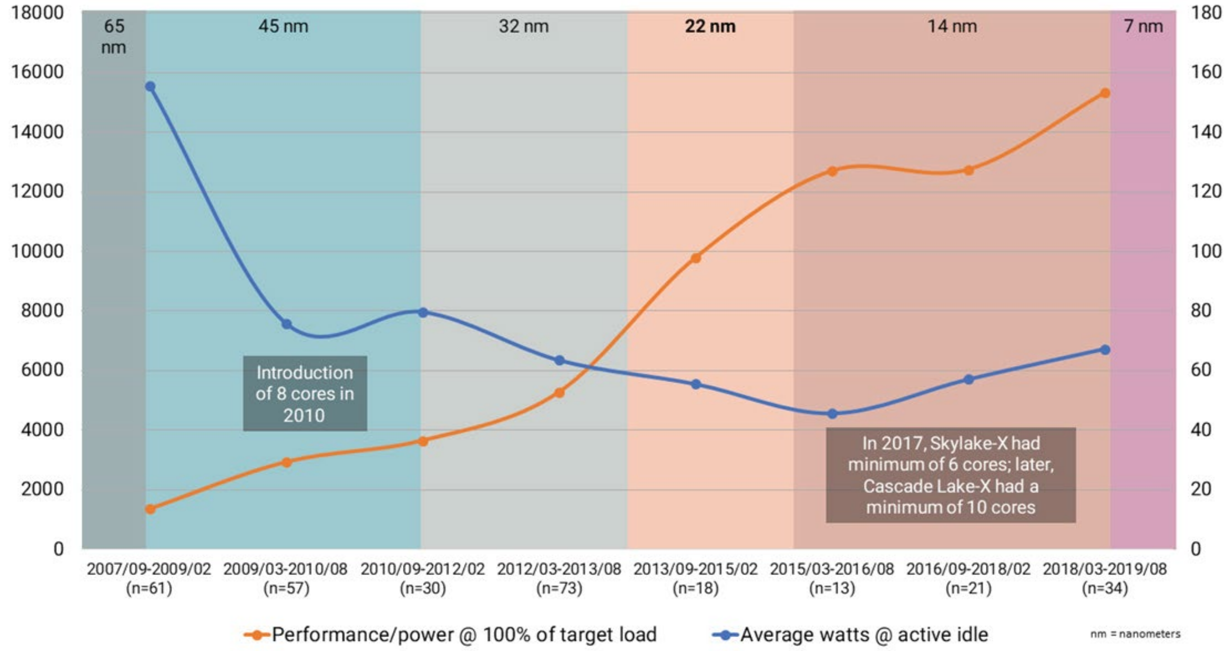


Figure 9. Performance vs idle power vs lithography. From Bashroush and Lawrence (2020)

Note. The color-coded vertical bars represent generations — lithography — of processor technology (usually, Intel). For each generation of around three to four years, hundreds of servers are released. The steeper the rise of the orange line (compute performance per watt), the better. For the blue line — power consumption at idle — the steeper the decline, the better.



Appendix 6. Energy savings from replacing older servers and operating with higher utilisation

Older server replacement

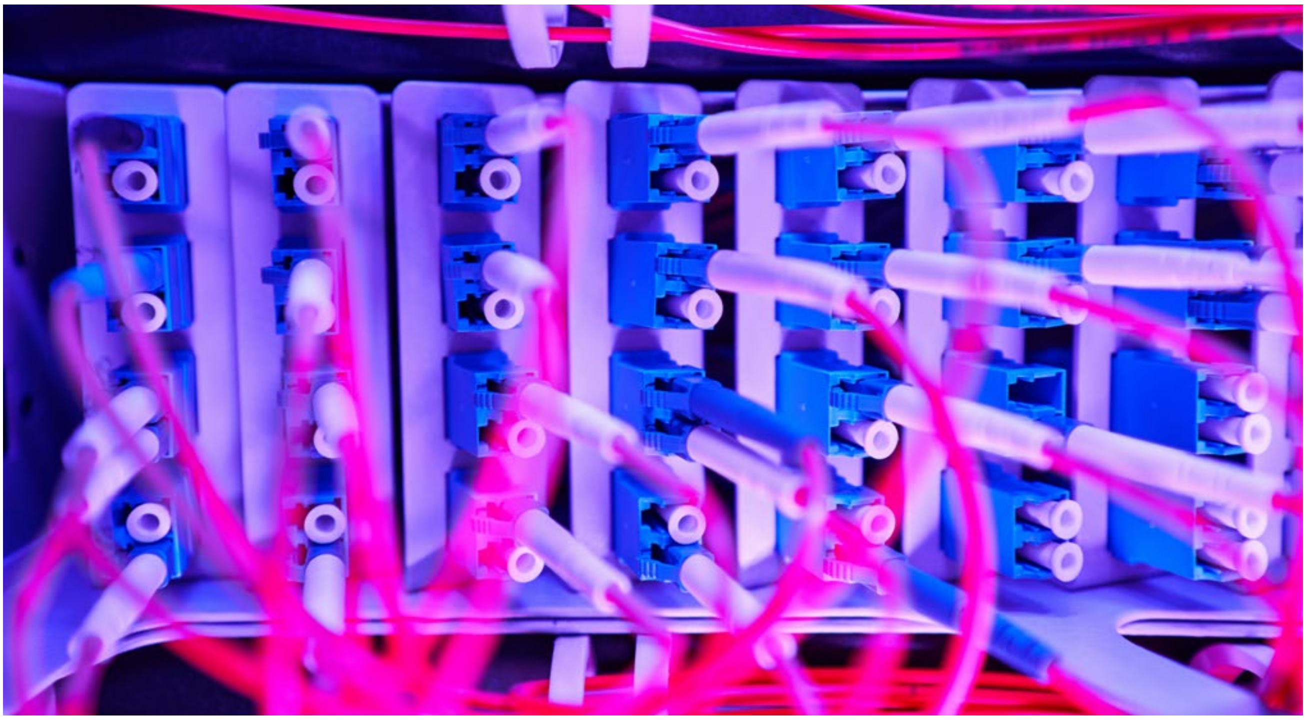
Bashroush and Lawrence (2020) examined the energy consumption of a fixed workload in different operating environments, using servers of varying age from current-generation equipment to nine-year-old kit. Various scenarios were analysed — from using old, under-utilized servers that were not virtualized, to using modern, highly utilized servers with full virtualisation. They found that the energy savings from replacing the oldest (nine-year old) equipment with servers in the most recent 'batch' under Moore's Law, (i.e. up to a year and a half old) were high, at between 78% and 86%.[1] The energy savings for 'mid life' equipment, four and a half years old were more modest, but still notable at between 16% and 18%.

The authors remark that "Moore's law is slowing down"–it has been harder for chip manufacturers to maintain the pace of improvement. They found evidence of this; they analysed a dataset containing energy performance results from hundreds of servers, based on the SPEC measurement tools. They found that server performance per watt was plateauing and average power use in idle mode has started to increase. This means that the high efficiency gains from server replacement will decrease for more recent servers but also that, as servers in real-life deployments tend to spend a substantial part of their time in idle, the focus should be on active idle efficiency rather than just on higher server performance efficiency.

However, they make the disclaimer that chip technology is a constantly changing landscape and it is possible that the rate of improvement may pick up again.

Increased utilisation

Bashroush and Lawrence used the same dataset to estimate energy savings from increased utilisation (achieved through consolidation and virtualisation, as described in the main text). They found that moving from low utilisation, (5%, the norm around 2010) to medium, (10% in enterprise, co-location and private cloud), the energy savings were around 40% and from low to high (25% in enterprise, co-location and private cloud) from 60 to 70%. They note that these benefits may not always be available — a careful analysis of workloads and capacity is needed.



1 This does not account for the embodied energy and related emissions in manufacturing the new servers.

Appendix 7. Data on current locations and factors affecting choice of location

Information was gathered from a range of sources covering different geographic regions.

International

Arcadis (a large multi-national design and engineering consultancy[2]) rate country's suitability for new data centres in their location index (Arcadis 2021). Countries are scored on eight factors, out of a maximum score of 100. The factors are:

- GDP per capita
- Dealing with construction permits
- Price of electricity
- Energy security
- Global cyber security
- Mobile-broadband subscriptions
- Domestic market size
- Mean download speed

The USA was top of the 2021 index with a score of 77.86; Australia was 14th in the ratings, between the UK and China, with a score of 61.56.

Cushman & Wakefield, a global commercial real estate services firm, produce an annual Data Center Global Market Comparison report (Imboden 2021). This considers the attractiveness of existing data centres by 48 city (or region e.g. Silicon Valley) locations in Africa, North and South America, Asia and Europe. These are assessed against twelve weighted criteria in three categories:

- real estate and physical considerations
  - development pipeline,
  - environmental risk,
  - land price,
  - vacancy
- ecosystem advantages
  - cloud availability,
  - fibre connectivity,
  - market size,
  - sustainability,
- and political and regulatory review
  - government incentives,
  - political stability,
  - power cost,
  - taxes.

The highest weighting is given to Cloud Availability, Fibre Connectivity and Market Size and the lowest to Environmental Risk, Land Price and Power Cost with the other six factors given medium weighting.

In 2021 the top ten locations in their ratings were:

- Northern Virginia
- Sydney
- Singapore
- London
- New York/New Jersey
- Chicago
- Silicon Valley
- Dallas
- Seattle
- Amsterdam

2 See Arcadis's web site for more information.

Table 15. Factors which influence data centre location attractiveness, Dutch Data centre Association (2020)

Grouping	Factor
Geography	Temperature
	Natural disaster risk
	Transportation and access
	Social, economic and political stability
	Proximity to HQ/business locations
Energy	Electricity supply quality
	Electricity prices
	Renewables
Proximity to major markets and customers	Population within 500 km
	Population within 1000 km
Telecom infrastructure	Submarine cables
	Fibre internet subscriptions (per 100 pop.)
	Internet Exchange
Other costs	Construction costs
	Property tax rates
Data centre redundancy	Data centre redundancy
Other factors	Labour costs and availability
	Quality of life
	Tax and regulatory climate

Europe

The Dutch Data Centre Association (2020) grouped locational indicators as shown in Table 15.

In their analysis each factor was given a weighting which was different for the type of data centre: multi-tenant, hyperscale and colocation, some of which are zero for some factors.

In 2018 the Norwegian government stated their ambition for Norway to be a 'data centre' nation (Norwegian Ministry of Trade, Industry and Fisheries, 2018). They gave a number of factors in their favour, including areas where they intended to make improvements which were:

– A stable, cold climate

– A stable electricity network

– A high level of renewable electricity supply

– A reasonable tax regime (they proposed some tax reforms that would benefit data centres)

– High quality broadband data connection (they listed their actions to encourage and enable this)

– Straightforward, well explained procedures for site development (they said they would produce guidance for planning and licensing)

– ICT expertise (they said they would put money into student places and ICT research)

– A public sector customer base (they have a policy for the public sector to use cloud computing unless there is an obstacle to do so)

– Access to the EU market as a member of the European Economic Area (EEA)

A study for the Nordic Council of Ministers by a consultancy, COWI, in the same year (Christensen et al 2018) found that eight factors were important for site selection, in four tiers of importance:

– Reliable power supply

– International data connectivity

– Low energy prices

– Political stability

– Time-to-market

– Abundance of energy and other resources

– Competent workforce

– Natural disaster-free climate.

They found that the Nordic countries performed well against these criteria and projected that the power capacity of new data centres in the Nordics per year would almost double, from 300MW in 2018 to nearly 600MW in 2025.

techUK (2020) consider the three factors which are most important for data centres to be:

– Power–a stable, high quality electricity supply

– Position–access to customers

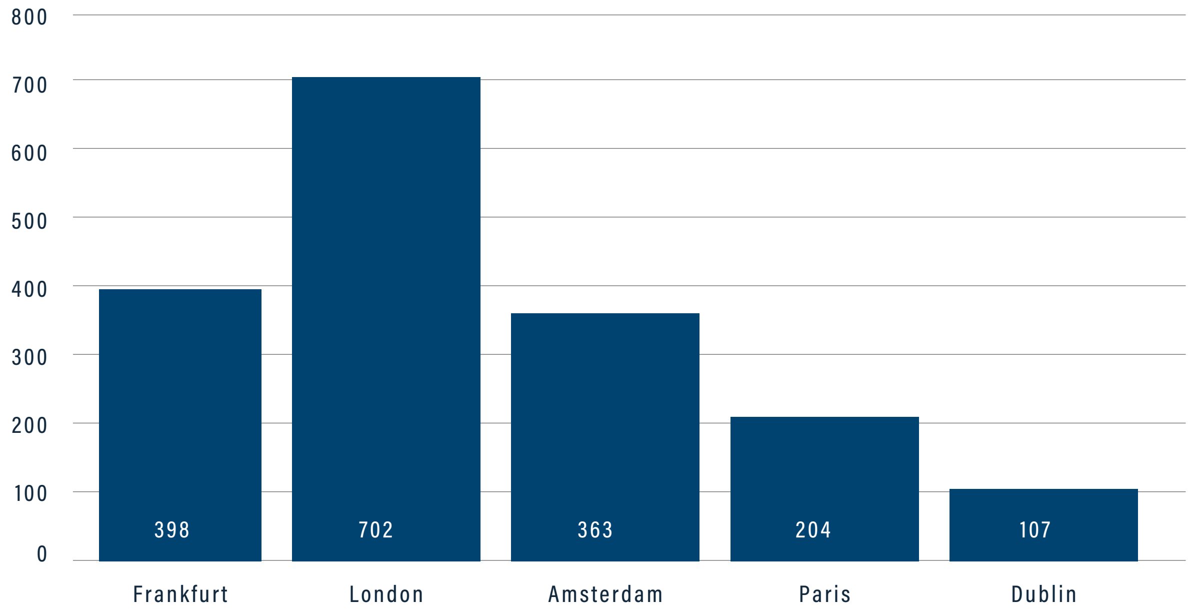
– Ping–digital connectivity

The UK scores well on all of these but techUK attributes the UK's success to the particular attractiveness of London, which is where the majority of data centres are located: "Informally we attribute London's pre-eminence to three things: Age, Beauty and Experience: Age is first mover advantage: by being first, London attracted key players and around them a complex ecosystem has developed. Beauty is the attractiveness of London for investors and for skilled staff seeking a career in the sector. Experience is London's world class expertise in investment, finance, design, engineering, construction, technical brokerage, procurement, compliance and energy management."

The European market is dominated by four metro centres, Frankfurt, London, Amsterdam and Paris, referred to by the acronym FLAP. Dublin is a recent entrant and has been exceptionally successful in attracting large cloud providers as well as colocation operators, so is now included in recent analyses. These "FLAP-D" data are a good proxy for the broader commercial data centre market in Europe. techUK data on data centre supply, using MW of take-up as a proxy, are reproduced in Figure 10.

techUK also provide this commentary on locational trends within Europe:

Figure 10. The European market–data centre supply, using MW of take-up as a proxy, from techUK (2020)



“Scandinavia is well placed to attract large hyperscale operators and although working from a small base, data centre markets are developing very rapidly in Sweden, Norway, Finland, Denmark and Iceland. These countries are competing fiercely for operators and investors to locate facilities and we have seen significant concessions made by nation state governments in the form of energy tax reductions, inward investor support and planning assistance. In Ireland, European head office location for many large cloud providers, data centres are now classified as infrastructure developments. In Sweden one regional initiative of note is Lulea, a post-industrial location close to the arctic circle, which has reinvented itself as a data centre hub and centre of excellence, welcoming investment from cloud operators, hosting a research facility and a technical university.”

“It is worth mentioning that the UK market and other traditional metro markets (Frankfurt, Paris and Amsterdam), differ from the Irish and Scandinavian business models. The former all host financial centres and data centres have coevolved with these and other digitally dependent industries, providing the infrastructure for their customers to deliver and export services. In newer markets like Dublin and Sweden, it is the operators themselves (e.g. Facebook, Apple, Microsoft and Google) that are selling software and software-based services.” techUK(2020)

North America

The CBRE North America report for the second half of 2020 (CBRE 2021a) provides data for seven major regions in the US as shown in Table 16.

Table 16. North America market capacity as at second half 2020 (CBRE 2021a)

US Region	Inventory (MW)
Northern Virginia	1377
Dallas/Fort Worth	361
Silicon Valley	292
Chicago	289
Phoenix	239
New York/ Tri state	149
Atlanta	164

In their 2020 year end report JLL (JLL 2021) gave a similar list of locations, with slightly different groupings (e.g. New Jersey and New York are listed separately) and some additional regions, namely:

- Northwest
- Houston
- Denver
- Los Angeles
- Austin/San Antonio
- Boston

Appendix 8. Descriptions of regulations, certification and other initiatives

Data centre regulation

China GB 40879–2021

On 11 October 2021, the China Standardization Administration (SAC) and the China State Administration for Market Regulation (SAMR) approved and published a new standard on Maximum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Data Centers, GB 40879–2021. This standard specifies the technical regulation on energy efficiency rating, energy consumption measurement, energy efficiency calculation and assessment of data centres.

This standard covers newly built, renovated and expanded data centres, individual or modular units of data centre buildings with independent power distribution, air cooling, and electric air-conditioning.

This standard does not apply to edge data centres. Data centres using other non-electric air-conditioning equipment are under the scope of this standard.

A superficial reading of the regulation is that it sets a maximum value of PUE of 1.5 (although more ambitious levels of 1.2 and 1.3 are also mentioned). This standard will apply from 1 November 2022.

To get a sense of the degree of ambition of this regulation this requirement can be compared to those reported in Appendix 3. Energy performance data. In this context, bearing in mind most of the values are for new and operational data centres, not just the new and refurbished data centres that the Chinese regulation applies to, the regulation seems likely to have some effect, although it is not very stringent.

Computer and other component regulation and certification

Computer servers

Two regulations for server efficiency have been identified:

1 in the EU, 2019/424, (European Union 2019) Ecodesign regulations for servers and data storage products, which was adopted in 2019. This sets minimum efficiency requirements for power supply units (PSU), and active state efficiency and maximum idle power levels in Watts.

2 In Japan, Standards for Determining Manufacturers and Other Companies of Energy Consumption Machines Concerning the Improvement of the Electronic Computer Performance in Terms of Fuel Consumption (Public Notice of the Ministry of Economy, Trade and Industry No. 69)[1] were announced in 2019. The information available in English is limited.

There are also two certification schemes for servers:

– In the US ENERGY STAR[2] (EPA, 2018) set the v3 specification which took effect in 2019. It set minimum requirements for efficiency for PSUs, and Active and idle state efficiency. Qualifying products must also offer processor power management.

– NSF International (NSF International, 2019) in NSF/ANSI 426 – 2019 set requirements for servers qualifying for EPEAT classification.[3] This sets the energy efficiency to match the current ENERGY STAR requirements. It also sets requirements for other ecological related impacts such as restricting toxic substances, designing for repair, considering end of life management and so on.

As stated above all of these schemes use SERT to measure IT equipment energy efficiency for servers (ITEE).

The test methodology for power supplies used for ENERGY STAR qualification is described in Mansoor et al (2018).

Computer storage

One certification scheme has been found for data centre storage. In the US ENERGY STAR (EPA 2020), set the v2 specification which took effect in March 2021. It set minimum requirements for efficiency for PSUs, energy efficiency active state requirements for Block I/O Systems and required adaptive active cooling. The measurement of energy efficiency requires the use of SNIA Emerald™ Power Efficiency Measurement Specification, Version 4.0 (SNIA 2020).

1 More information
2 An endorsement label – all qualifying products and companies can display the ENERGY STAR label
3 An international environmental label with three levels of conformance: Bronze, Silver and Gold

Uninterruptible Power Supplies/Systems (UPS)

One certification scheme has been found for UPSs. In the US ENERGY STAR (EPA 2017), set the v2 specification which took effect in January 2019. It sets minimum requirements for efficiency for PowerSupply Units.

In addition there is an EU Code of Code conduct for UPSs (JRC 2021a) which sets minimum energy efficiency levels for participants in the code.

HVAC and energy loss component

There is a building code which sets minimum requirements related to HVAC systems for data centres which operates in California USA, the most recent version being in 2018. (California Energy Commission 2018). Section 140.9 – prescriptive requirements for covered processes sets requirements to include: economizers; have controls to prevent reheating; prohibit nonadiabatic humidification, set a maximum value for the power consumption of fans; require fans in unitary air conditioners to have controls and include air barriers.

Proposed changes to the 2022 code, which would take effect from 1 January 2023, include tightening the economizer requirements and setting requirements for Uninterruptible Power Supply (UPS) efficiency.

ASHRAE have developed a model building code for the US, Standard 90.4: Energy Standard for Data Centers, updated in 2019,[4] which sets the minimum efficiency requirements for heating, ventilation and air conditioning systems and electrical systems in data centres. This is a performance-based design standard that offers the design components for mechanical load (MLC) and electrical loss (ELC). Calculations of the MLC and ELC are made and then compared to the maximum allowable values, which vary across different climate zones. Compliance with Standard 90.4 is achieved when the calculated values do not exceed the values contained in the standard. An alternative compliance path is provided that allows trade-offs between the MLC and ELC.[5]

Individual State Governments in the US may choose to adopt part or all of ASHRAE codes. The HVAC and ELC components of the 2016 version of code 90.4 is known to have been adopted in the Washington State Building Code in 2018 (Washington State Building Code Council, 2020). (It is beyond the scope of this review to establish whether or when other States or Governments may also have adopted this code.) Measurement standards for computer servers, data storage, power supplies and related to HVAC systems are in listed in Appendix 1. Standards listing.

Data centre certification schemes which include energy efficiency

This section provides more detail on the schemes outlined in Table 5.

Blue Angel: Energy Efficient Data Center Operation DE-UZ 161

The Blue Angel[6] is the ecolabel of the German Federal government and has been operational since 1978. It is an endorsement label; if 'products' meet the requirements they are allowed to display the label. The data centre operation label first became effective in January 2019. It is awarded to a physical building and only to data centres where the operators and/or service providers of data centres who have an influence over all areas and systems of a data centre ie not suitable for Colocation. The label energy efficiency criteria are PUE of the data centre and the EER of the cooling system. IT related criteria are: an IT inventory list; a minimum utilisation load (IT Equipment Utilisation for Servers); maximum idle power and minimum active energy efficiency of servers; energy efficient external power supplies. Another requirement is that all electricity must be supplied from renewable sources or decentralised combined heat and power plant.

Certified Energy Efficient Data Center Award (CEEDA)

CEEDA,[7] a voluntary label, was launched by BCS (The Chartered Institute for IT[8] (the date of founding is not clear from the scheme web site – it appears to be 2015 or 2016 from the references and dates of certificates issued.). The awards are in three classes (bronze, silver and gold) for

4 The 2019 revision added addenda to the standard as follows: Addendum a encourages recovery of waste heat from data centres for use in space heating and industrial applications, resulting in net energy savings on a societal level. Addendum b clarifies exactly how credit can be taken for renewables. The renewables credit is limited to 5% of the IT load in order to encourage renewable energy while still requiring energy efficient mechanical and electrical systems. Addendum d clarifies definitions related to types of UPS utilised by end users and the requirements related to those. Addendum e adds language to Section 11 intended to clarify how compliance with Standard 90.4 can be achieved through the use of shared systems. Addendum f modifies Section 5.2.1 to add specific language about building envelope criteria for data centres and how it is to be accounted for in the MLC calculations.

5 The International Energy Conservation Code (IECC) points to design load requirements in ASHRAE 90.4 (IECC C403.1.2).

6 More information

7 More information

8 More information

four categories of award, three for existing data centres: enterprise, Colo, Telco and design/operate for new data centres. It incorporates best practices, standards and metrics from: ENERGY STAR Server Specification 2.0 (or above), SERT V1.1.1, EU COC 2016 Guidelines V7.1.2, Green Grid: PUE, WUE onsite, WUE source, Energy Reuse Effectiveness (ERE),[9] CUE, Green Energy Co-efficient (GEC);[10] ETSI EN 3.1; EN 300 019, ASHRAE TC 9.9, Classes, 2, 3, 4; ISO: 55000, 14001, 50001, 55000; IEC 30134, 14040 and ITU TL1300, L.1310–201408 (most of which are included elsewhere in the report)

DCA Certification Scheme

This is a voluntary certification standard developed and operated by the DCA (Data Centre Alliance) an international trade association for the data centre sector.[11] The scheme started in 2013; the current guidelines were issued in 2020 (DCA, 2020). The certification criteria include resilience class, operational integrity, and site physical security as well as energy efficiency. For the last of these, PUE value is not used as a criterion but it is required to be reported as a useful indicator of performance. Certification requires the operator to demonstrate that they are following one of three energy efficiency strategies: Green Grid Maturity Model (level 3 or better); EU Code of Conduct Ver10 or later or ITU (International Telecommunications Union) L 13.

Fossil Fuel Data

This is a voluntary certification standard developed and operated by Node Pole, a Swedish consultancy company. In order to qualify for the label,[12] companies must meet the following criteria:

- 100% renewable energy supply
- Power Usage Effectiveness ≤1.4
- Carbon Usage Effectiveness of less than 0.19 kg carbon emissions per kWh IT energy

Green Data Centre Standard SS 564 Singapore

This is a voluntary certification standard.[13] Development was led by Infocomm Media Development Authority of Singapore partnered with other government agencies and industry, first published in 2011 and revised in 2013. It is modelled after the ISO 50001 standard on energy management, specifically tailored to meet the needs of DCs in Singapore. The standard adopts the Plan-Do-Check-Act methodology, an iterative, four step problem-solving process used for continuous process improvement.

Swiss Data Center Efficiency Label

The Swiss industry association digitalswitzerland and Hewlett Packard Enterprise (HPE) founded the Swiss Datacenter Efficiency Association[14] to own the assessment and award process for this voluntary label, which was launched in 2020. The initiative is supported by the Swiss Federal Office of Energy through the programme SwissEnergy. The label has three grades for efficiency (bronze, silver and gold); in case of compliance with the environmental sustainability criteria, the carbon footprint, (the end-to-end carbon emissions of the DC reported in grams per kWh of consumed electricity) a “plus” tag is added to the awarded level.

The two efficiency criteria (Swiss Datacenter Efficiency Association, 2020) are IT infrastructure efficiency and DC infrastructure efficiency. The former captures the efficiency of the primary IT components including compute, storage, network and their utilisation. The latter takes into account PUE and recycling capabilities.

Building Focused data centre certification schemes

Sub section note. These certification schemes, being building focused, include criteria which are not specific to data centres, such as: transport, health and well being, pollution, land use and ecology, and materials. The descriptions in this section focus solely on the criteria particular to data centres and omit these broader considerations

BCA-IDA Green Mark for Data Centres, Singapore

This label was jointly developed by Building and Construction Authority (BCA) and the Infocomm Development Authority (IDA) of Singapore (BCA-IDA, 2012). There are four levels of certification (certified, Gold, Gold plus and platinum) depending on points scored. The major energy related criteria are: PUE and Peak Data Centre Cooling Load (expressed as kW/Refrigerated Ton). Other, lower scoring criteria include: on the air handling system; minimum IT power chain efficiency; use of ENERGY STAR related servers, storage devices and network systems. Refers to SS564 Green Data Centre Standard (see above).

9 Directly related to Energy Reuse Factor, ERF
10 More commonly referred to as the Renewable Energy Factor, REF
11 More information
12 More information
13 More information
14 More information

BEAM Plus New Data Centres and Existing Data Centres

BEAM Plus is a certification scheme for buildings developed for and operational in Hong Kong but also used in some regions of mainland China. There are separate schemes for new and existing data centres; both of which were introduced in September 2021 (BEAM, 2021a and BEAM 2021b). The main energy related requirements for new data centres are a minimum PUE of 2 (additional credits for lower values) and requirements for energy efficiency of air conditioning and lighting. For existing data centres credits are given for a PUE of 2 or lower.

BREEAM SD 5068 Data Centres 2010

BREEAM certification is operated by BRE Global. There are five benchmark levels from pass to outstanding based on points scored across a range of criteria. BRREAM Data centres (BREEAM, 2012) covers new builds, extensions & major refurbishment and building fit-out (ie it is not suitable for operational data centres). Points related to energy are awarded based on PUE and CO2 index taken from the Energy Performance Certificate.

It is worth noting that BRE Global announced the launch of the BREEAM Data Centres Annex Pilot in November 2019[15] but no further announcements have been made since then. Also BREEAM certification generally operates internationally but the data centre version references data from the UK Energy Performance Certificate (EPC),[16] which suggests that this may only apply to the UK.

Energy Conservation Building Code (ECBC) in data centers, India

The building energy code (ECBC) in India is currently voluntary. The Confederation of Indian Industry (CII), Indian Green Building Council, and the Lawrence Berkeley National Laboratory have been developing the code for data centres over several years and released a final draft User Guide for Implementing ECBC in data centres in December 2020 (CII et al 2020). It is not clear from publicly available information whether the code is operational.

There are three efficiency levels: ECBC Compliant, ECBC+ and SuperECBC. PUE is used as the overall measure of energy performance. Points are also awarded against the efficiency of: room cooling; chiller plant; electrical system and IT hardware and IT system management (including mean CPU Utilisation)

ENERGY STAR score for data centers, USA

ENERGY STAR for buildings is both a benchmarking and a certification scheme. The ENERGY STAR score shows how a building is performing against similar buildings nationwide (USA) A score of 50 represents median energy performance, while a score of 75 or better indicates a building is a top performer — and may be eligible for ENERGY STAR certification.[17] The ENERGY STAR scoring for data centers was first released in June 2010. The most recent Technical Reference is 2018 (ENERGY STAR Portfolio Manager 2018). The dependent variable for data centres (the predicted value given other variables such as size and IT energy) is PUE.

It has been reported[18] that data centres have emerged as the fastest-growing sector for ENERGY STAR certification, with more than a four fold increase between the number of data centres certified in 2014 and 2018; 100 data centres were certified in 2018.

Green Building Index (GBI) for Data Center, Malaysia

GBI is a wholly-owned subsidiary of Pertubuhan Akitek Malaysia[19] (PAM) and the Association of Consulting Engineers Malaysia (ACEM). GBI assessment criteria for data centres were published in 2013 (GBI, 2013). There are four classifications: certified, silver, gold and platinum. Data centre specific energy efficiency related points are awarded on the basis of PUE or Building Energy Index (BEI) or a combination of achieved PUE/BEI and improvement in performance over the last three years. Renewable energy supply is awarded additional points.

Indian Green Building Council Data Center rating system

The Indian Green Building Council (IGBC) is a part of the CII.[20] They issued a Rating System Pilot Version, Abridged Reference Guide for data centres in 2016 (IGBC 2016). Four levels of rating are awarded: certified, silver, gold and platinum. New and existing data centres can be rated. Minimum energy efficiency requirements are set on PUE; PUE below these thresholds are awarded points. Renewable energy supply is awarded additional points.

LEED (Leadership in Energy & Environmental Design) Data Centers

Developed by the U.S. Green Building Council, LEED is a framework for identifying, implementing, and measuring green building and neighbourhood design, construction,

15 More information
16 The EPC is a standardised building energy rating which is compulsory when constructed, sold or let.
17 More information
18 LBNL Center of Expertise for energy efficiency in data centers, ENERGY STAR Data Centers.
19 Malaysian Institute of Architects.
20 More information

operations, and maintenance which operates internationally. Four levels of rating are awarded: certified, silver, gold and platinum. New data centres can be rated against BD+C (Building Design and Construction) criteria; existing data centres against O+M (operation and Maintenance) criteria. A review of the BD+C criteria shortly after its introduction (Izadi Moud et al 2018) found that relatively few of the criteria had been made specific to data centres, only energy performance and thermal comfort. The Moud et al paper implies that PUE is used as the main energy performance metric.

NABERS for data centres, Australia

NABERS ratings gives data centres a rating from one to six stars. The rules were issued in 2014 (NABERS, 2014). Three types of NABERS Energy for data centres ratings are available: IT equipment rating; infrastructure rating and whole facility rating. A recent fact sheet (NABERS, 2020) indicates that the infrastructure rating is on PUE. The IT equipment rating assesses the energy efficiency of the storage, processing and network equipment of the data centre (expressed as kWh per unit storage/processing capacity), the whole facility rating combines both IT Equipment and Infrastructure. The scheme operators have indicated that Colos generally choose to adopt the infrastructure rating.

Lindsay et al (2021) report energy use for NABERS rating and PUE for eight data centres with NABERS data centre infrastructure ratings from the publicly available NABERS register.[21] When accessed by the author in January 2022 the register included nine premises, with PUE values of between 1.3 and 1.7.

Other data centre initiatives (voluntary commitment, procurement, government)

Climate Change Agreement for the Data Centres Sector, UK

The Climate Change Agreements (CCA) scheme aims to promote energy efficiency in energy intensive industry while protecting the competitiveness of these industries. The voluntary scheme offers companies with energy intensive processes significant discounts on the Climate Change Levy (a carbon tax) in return for meeting energy or carbon efficiency targets agreed between Government and sectors.[22] The scheme is operated by the Environment Agency for the UK Government (Department for Business, Energy and industrial Strategy). Organisations participate in the agreement via the relevant trade association, in this case techUK, via an Umbrella Agreement (Environment Agency 2017). The Agreement is only open to Colos. The sector target for data centres is a 15% reduction in PUE by 2020 from the base year (techUK 2017).

Data Center Accelerator and Better Building Challenge, USA

The Data Center Accelerator was led by Better Buildings, part of the US Department of Energy (DOE). They worked with both public and private sector building data centre owners and operators to accelerate the adoption of system metering and associated energy tracking and reduction, while developing best practice approaches for various data centre configurations and demands. The Accelerator ran from 2015 to 2020.

Data Center Accelerator Partners committed to improve the energy efficiency of infrastructure of one or more data centres of 100 kW or greater IT load by at least 25% within 5 years.

DOE helped Accelerator Partners by:

- Providing technical expertise and training, with the help of Lawrence Berkeley National Lab.
- Providing a repository for relevant best practice and research documents
- Creating networking and technical opportunities to help Accelerator Partners share innovative solutions
- Facilitating the sharing of best practices across the industry
- Featuring partners who leveraged, developed, and shared innovative and cost-effective energy efficiency solutions.
- Providing national recognition to partners commensurate with energy efficiency results achieved.

On average, partners achieved a 36% improvement in their data centre's infrastructure energy surpassing the Accelerator's original goal, resulting in $3.9 million in annual cost savings. The lessons learnt from the Accelerator have been captured in the Data Center Accelerator Toolkit[23] – a collection of guidance, factsheets, best practices, and other resources.

21 NABERS register
22 UK Government guidance on Climate change agreements.
23 which is still running – more information

The Better Building Challenge[24] has some similarities with the accelerator; Partners are challenged to reduce energy use throughout their portfolios by at least 20% over 10 years. They also agree to share their annual progress and their solutions that provide replicable models for others to follow. Data Centres are one of nine market sectors included in the challenge.

EU Code of Conduct on Data Centre Energy Efficiency

The EU Code of Conduct (CoC) was started in 2008 and is operated by the Joint Research Council (JRC), part of the European Commission.[25] There are currently (July 2021) over 400 participants. Organisations can apply to join the CoC as participants (owners and operators of data centres) or as endorsers (committing to support the Code and participants through the development of products, information, services, education or other programs) (JRC 2021b).

Participants sign a registration form, through which they commit to conduct an initial energy audit to identify the major energy saving opportunities, prepare and submit an action plan and implement this plan according to the agreed timetable. Energy consumption must be monitored regularly to see over time progress in the energy efficiency indicator related to the data centre. All Participants are required to follow the best practice guidelines (Acton et al 2021) which are updated annually, and to report against these guidelines annually. They have an obligation to continuously monitor energy consumption and adopt energy management in order to look for continuous improvement in energy efficiency. One of the key objectives of the CoC is that each participant benchmark their efficiency over time, using the CoC metrics in order to produce evidence of continuous improvement in efficiency. Analyses of data submitted by participants from 2009 to 2016 are reported in Avgerinou et al 2017.

In addition, every year data centres that have adopted innovative technologies to improve their energy efficiency and have demonstrated outstanding improvements are given the Code of Conduct Data Centre Award. The criteria for the winners are the reduced need for mechanical cooling of the data centre for most of the time and raised indoor temperature. These are among the most important measures to improve efficiency and reduce energy consumption.

Energy efficiency targets (expressed as PUE) are complemented by general commitments to monitor power and energy consumption, adopt good management practices, increasing IT utilisation, switching off components not needed, and reducing energy consumption where possible.

EU Climate Neutral Data Center Pact

This is a self-regulatory initiative by the EU data centre industry. Cloud Infrastructure Service Providers in Europe (CISPE) and the European Data Centre Alliance (EUDCA) have created a governance coalition known as the Climate Neutral Data Centre Pact.[26] Signatories to the Pact may be trade associations representing data centre operators or companies that own or operate data centres within the European Union. Beginning January 1, 2021 representatives from the data centre trade associations and companies that have signed the initiative, and the European Commission will meet twice annually to review the status of this initiative. By no later than July 1, 2023, signatories will certify adherence.

Climate Neutral Data Centre Pact (2021) states the requirements are:

- Energy efficiency, using PUE as a metric
- Matching electricity use by purchasing clean energy (clean energy)
- Setting and meeting ambitious targets for water usage effectiveness
- Increasing the quantity of server materials repaired or reused and creating a target percentage for repair and reuse (circular economy)
- Exploring possibilities to interconnect with district heating systems and other users of heat

EU Proposal for a Directive on Energy Efficiency (recast)

In July 2021 the European Commission proposed a recast of the Energy Efficiency Directive (EED) (EC 2021) which included a requirement for large data centres (with a power requirement of 1MW or greater) to make an annual disclosure of key sustainability information to the respective Member State, which would then be published. They proposed four sustainability indicators: how efficiently it uses energy, how much of that energy comes from renewable energy sources, the reuse of any waste heat that it produces and the usage of freshwater. The Annex to the draft

24 More information
25 JRC data centre code of conduct
26 CNDCP rules

directive (EC2021a) specifies the information required in more detail, adding:

- the name of the data centre;
- the name of the owner and operators of the data centre;
- the municipality where the data centre is based;
- the floor area of the data centre;
- the installed power;
- the annual incoming and outgoing data traffic; and
- the amount of data stored and processed within the data centre.

The proposal also includes an obligation for newly planned and substantially refurbished data centres to assess the viability of using waste heat on a site-by-site basis.

DIGITALEUROPE, which describes itself as "the leading trade association representing digitally transforming industries in Europe", responded largely positively to the proposal (DIGITALEUROPE, 2021). They proposed that the information requirement should cover more data centres by setting a lower threshold for reporting of 100kW. However they state that "reporting on "data stored and processed" and "data traffic" is "challenging or even impossible" and ask that the Commission identify more suitable indicators, with support from their members.

EU green public procurement criteria for data centres, server rooms and cloud services

The European Commission has developed green public procurement (GPP) criteria in recognition of the fact that Europe's public authorities are major consumers and so can influence the market for goods and services. By using their purchasing power to choose environmentally friendly goods, services and works, they can make an important contribution to sustainable consumption and production.[27]

GPP for data centres were published in 2020 (European Commission, 2020) alongside the technical report describing their development (Dodd et al 2020). Criteria can be a selection criteria (SC, that is products not meeting these requirements are not eligible for purchase) or award criteria (AC that is points are awarded against these; products with higher scores are selected for purchase). Further, there are 'core criteria' that must be included and more demanding ambitious 'comprehensive criteria' that public authorities can choose to use.

Energy related technical specifications included in the EU GPP are:

- Server active state efficiency, SC
- Where air cooling is used, ICT Operating range – temperature and humidity, SC
- Demonstrate that the facility has environmental control facilities and infrastructures that are in line with the requirements and recommendation of standard EN 50600-2-3, SC
- Server idle state power, AC
- Renewable energy factor, AC

Required operational and competencies (all SC) are:

- relevant competencies and experience in optimising a server's utilisation
- relevant competencies and experience in minimising cooling energy use, identifying opportunities to reduce energy use and to use any remaining waste heat
- demonstrate waste heat reuse readiness (if there is ready demand on or near site for the heat)

There are also contract performance clauses. If the contractor operates the data centre they must:

- Undertake periodical reporting of optimisation analysis and the achievement of utilisation targets.
- Measure and report monthly the utilisation rate of the servers in the data centre based on ISO 30134-5
- Provide an annual report containing the year's average and monthly disaggregated data for the total metered energy consumption of the data centre and the sub-metered electricity consumption for the mechanical & electric systems and the IT equipment (to allow robust calculation of PUE)
- Provide monthly data for the renewable energy purchased or the renewable energy generated (if relevant)

27 European Commission commentary on the role of Green Public Procurement

Energy Saving Obligation – commercial data centers, the Netherlands

Organisations in the Netherlands which are large energy users[28] are obliged to adopt energy saving measures with a payback period of 5 years or less under the Energy Savings Obligation scheme, which was introduced in 2019. The Netherlands Enterprise Agency, on behalf of the Ministry of Economic Affairs and Climate, produces lists of 'recognised measures', customised for each of 19 sectors, including one for commercial data centres (Netherlands Enterprise Agency, 2020). Organisations are required to report which of the measures they have adopted. For data centres the list includes eight measures which are specific to server rooms as well as broader measure, such as insulating the building and using energy efficient fans in ventilation. The eight server room measures are:

- FD1 Matching the deployment of servers in server room to demand.
- FD2 Working with a higher cooling temperature by separating warm and cold air in the room.
- FD3 Operating at higher cooling temperatures by avoiding mixing of hot and cold air at unused positions in racks.
- FD4 Limiting the speed of fans in room coolers
- FD5 Applying energy-efficient cooling installation for cooling server rooms.
- FD6 Achieving higher refrigeration temperatures to increase efficiency of compression refrigeration plant and to make greater use of free cooling (below 12/13°C outside air temperature).
- FD7 Applying free cooling to reduce compression refrigeration plant operating time
- FD8 Applying free cooling in server rooms to reduce cooling plant operating time

An initial evaluation of the obligation has been published (Damhuis and de Gier, 2020) but this does not provide any information specifically about the response from the Commercial Data centre sector.

France finance law 2021 provisions for data centres

The French finance law 2021 (passed in 2020) includes article 167,[29] which makes provision that from 1 January 2022 data centres may be exempt from a tax charged on electricity (under article 266 of the customs code[30]) providing they adhere to a programme of good practice in energy management of data centres recognized by a public, national or international authority. As of April 2021 it was not clear what, if any programme, qualifies; it has been suggested that becoming a member of the EU CoC would meet this requirement.[31]

New South Wales requirement for minimum NABERS rating for owned or operated data centres

The New South Wales (NSW) Government Resource Efficiency Policy (State of NSW and Office of Environment and Heritage 2019) includes a requirement that data centres owned or leased by government agencies achieve NABERS Infrastructure and IT Equipment rating of at least 4.5 stars. This was required to be achieved and maintained by June 2020 or within 18 months of first occupancy.

Sustainable Public Procurement guidance for guidance for Networks, Telephone Services and Telephone Equipment,[32] the Netherlands

Public sector procurement support for data centres is provided by a web tool, available at https://www.mvicriteria.nl/en/webtool?cluster=1#//9/1//en.

There are different types of criteria:

- EIS = Minimum requirement
- GC = award criteria
- GE = eligibility requirement.
- SUG = suggestion,
- CB = Contract Provision.

Provisions include minimum requirements of PUE 1.3 (with an optional more stringent requirement of 1.2); and components meeting ENERGY STAR criteria where relevant.

28 That is, which consume 50,000 kWh of electricity or 25,000 m³ of natural gas (equivalent) per year. There are exemptions, for example for participants in the EU Emissions Trading Scheme.
29 The text of article 167 (in French)
30 The text of article 266 (in French)
31 Data Centre Magazine article, Bernard Lecanu, April 2021, Code of Conduct » Européen pour une meilleure efficacité énergétique dans les centres de donnée, (in French)
32 This includes data centres

Three-year Action Plan for the Development of New Data Centers (2021–2023)

In July 2021 there was an announcement[33] by the Chinese Government (National Energy Administration of the Ministry of Industry and Information Technology) on data centres. No information has been found in English – the text has been translated by Google Translate. Based on a brief review, the primary intention of the Action Plan is to:

- plan data centre expansion
- increase utilisation rates to 55%
- increase energy efficiency, with new data centres having a PUE of less than 1.35
- increase supply of energy from renewable sources
- consolidate data centres
- formulate comprehensive energy evaluation standards for data centres

USA Federal Data Center Optimization Initiative (DCOI)

This is a continuation policy from initial Federal Data Center Consolidation Initiative, which was launched in 2010 and which reduced energy use by consolidating and closing (less efficient) Federal data centres. The DCOI was established in 2016 and then revised in 2019 (Executive Office of the President Office of Management and Budget 2019). The policy set updated performance metrics of: virtualization; advanced energy metering; server utilisation and availability. It removed metrics on: energy efficiency (as measured by PUE, recognising that "is not always appropriate for comparison across multiple facilities or agencies" although "Improvement in PUE over time should be included in the agencies' approach to their data center management") and facility utilisation. The memo also asked agencies to consider buying EPEAT-registered servers when upgrading or replacing hardware to maximize energy efficiency.

Agencies are obliged to plan and report in several ways[34] under the initiative:

- A full inventory quarterly[35]
- An annual strategic plan
- Five milestones per fiscal year at a minimum

The initiative operates under the framework of the Federal Information Technology Acquisition Reform Act (FITARA).[36]

USA Federal Open Data Initiative

The US 2020 Energy Act stated that the Department of Energy and the Office of Management and Budget: "shall establish an open data initiative relating to energy usage at federally owned and operated data centers, with the purpose of making the data available and accessible in a manner that encourages further data center innovation, optimization, and consolidation." (Hoffman et al 2021). The author has not found reports on how this requirement is being met.

33 Notice of the Ministry of Industry and Information Technology on Issuing the "Three-year Action Plan for the Development of New Data Centers (2021–2023)"
34 Data Center Optimization Initiative Data Center Inventory (requirements for quarterly reporting).
35 Data Center Statistics are published by ITDASHBOARD.gov
36 Web page for Management and Oversight of Federal Information Technology

References

Acton M (2019) Data Centre Standards, Data Centre Alliance

Acton M, Bertoldi P, and Booth J (2021) Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency, Joint Research Council

Almoli A (2013) Air Flow Management inside Data Centres, The University of Leeds School of Mechanical Engineering

Alsop P (2021) editorial in Datacentre Solutions (magazine) Issue 1, April 2021, Angel Business Communications Ltd

Arcadis (2021) The Arcadis Data Center Location Index 2021

Ascierto R and Lawrence A (2020a) Uptime Institute global data center survey 2020, Uptime Institute

Ascierto R and Lawrence A (2020b) Five data center trends for 2021, Uptime Institute

ASHRAE Technical Committee (TC) 9.9 (2016) ASHRAE TC9.9, Data Center Power Equipment Thermal Guidelines and Best Practices, Whitepaper

ASHRAE (2020) ASHRAE TC 9.9 Technical Bulletin: Edge Computing: Considerations for Reliable Operation

Avgerinou M, Bertoldi P and Castellazzi L (2017) Trends in Data Centre Energy Consumption under the European Code of Conduct for Data Centre Energy Efficiency, Energies 2017, 10, 1470, DOI

Bashroush R, and Lawrence A (2020) Beyond PUE: Tackling IT's wasted terawatts, Uptime Institute

BCA-IDA (2012) BCA-IDA Green Mark for Existing Data Centres, Version EDC/1.0

BEAM (2021) BEAM Plus New Data Centres Version 1.0

BEAM (2021a) BEAM Plus Existing Data Centres Version 1.0

BEIS (2020) Evaluation of the second Climate Change Agreements scheme, Synthesis report, BEIS Research Paper Number 2020/01

Belady C (Editor), Azevedo D, Patterson M, Pouchet J, and Tipley R (Contributors) (2010), Carbon Usage Effectiveness (CUE): A Green Grid Data Center Sustainability Metric, The Green Grid

Bizo D (2019) The Carbon Reduction Opportunity of Moving to Amazon Web Services, 451 Research (commissioned by AWS)

Bizo D, Ascierto R, Lawrence A and Davis J (2021) Uptime Institute Global Data Center Survey 2021

BREEAM (2012) Data Centres Scheme Document SD 5068 issue 1.2

Bruschi J, Rumsey P, Anliker R, Chu L, and Gregson S (2011) Best Practice Guide for Energy-Efficient Data Center Design, US Federal Energy Management Program

The California Energy Commission (2018) Building Energy Efficiency Standards for Residential and Non-residential Buildings, for the 2019 building energy efficiency standards, Title 24, Part 6, And Associated Administrative Regulations In Part 1.

CBRE (2021a) A Source of Stability: Digital Infrastructure in 2020, North American Data Center Report H2 2020

CBRE (2021b) Europe Data Centres Q4 2020

CEN/CENELEC/ETSI Coordination Group on Green Data Centres (2020) Review of standardisation activities: Energy Management and Environmental Viability of Data Centres v7

Chinese Institute of Electronics (2020) China Green Data Center Development Report 2020

Christensen JD, Therkelsen J, Georgiev I and Sand H (2018) Data Centre Opportunities in the Nordics: An analysis of the competitive advantages

CGG (2021) Operational Considerations for Single-Phase, Immersion-Cooled Data Centers: A Client's Perspective, for GRC (Green Revolution Cooling)

CII, IGBC, and LBNL (2020) User Guide for Implementing ECBC in data centers, complying with the Energy Conservation Building Code (2017) and Higher Rating Levels, Version 8.0 (Final Draft)

Climate Neutral Data Centre Pact (2021) Climate Neutral Data Center Pact – Self Regulatory Initiative

Consumer Research Associates (2014) Energy Efficiency Policy Options for Australian and New Zealand Data Centres, for the Equipment Energy Efficiency (E3) Programme

Copenhagen Centre on Energy Efficiency (2021) Innovative Data-Centre Cooling Technologies in China – Liquid Cooling Solution

Damhuis E and de Gier M (2020) Evaluation: Information obligation Energy saving, Kantar (for Rijksdienst voor Ondernemend Nederland)

DCA (2020) The DCA Data Centre Certification Scheme: Guidelines for DATA CENTRES v2.37

DDA (Dutch Data Center Association), (2020), Data center GIDS 2020

DIGITALEUROPE (2021) Working together towards climate-neutral data centres: DIGITALEUROPE's views on the Energy Efficiency Directive

Dutch Data Centre Association (2020) State of The Dutch Data Centers 2020

Dodd N, Alfieri F, Gama Caldas M, Maya-Drysdale L, Viegand J, Flucker S, Tozer R, Whitehead B, Wu A, Brocklehurst F (2020), Development of the EU Green Public Procurement (GPP) Criteria for Data Centres, Server Rooms and Cloud Services, JRC,
DOI 10.2760/964841

EC (2021) Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on energy efficiency (recast)

EC (2021a) Annexes to the Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on energy efficiency (recast)

Eco (2013) Data Centre Star Audit

Energy Efficient Strategies and Maia Consulting (2014) Energy standards and labelling programs throughout the world in 2013, Department of Industry, Australia

Energy Information Administration (2021) 2018 CBECS (Commercial Buildings Energy Consumption Survey) Data Center Pilot Results

ENERGY STAR Portfolio Manager (2018) ENERGY STAR Score for Data Centers in the United States, Technical Reference

Environment Agency (2017) UMBRELLA CLIMATE CHANGE AGREEMENT FOR THE DATA CENTRES SECTOR

EPA (2012) Understanding and Designing Energy-Efficiency Programs for Data Centers

EPA (2017) ENERGY STAR® Program Requirements for Uninterruptible Power Supplies (UPSs), Partner Commitments

EPA (2018a) ENERGY STAR® Program Requirements for Computer Servers Partner Commitments

EPA (2018b) ENERGY STAR Score for Data Centers in the United States

EPA (2020) ENERGY STAR® Program Requirements for Data Center Storage Partner Commitments

European Commission (2020) EU green public procurement criteria for data centres, server rooms and cloud services, European Commission, DOI 10.2760/964841

European Union (2019) COMMISSION REGULATION (EU) 2019/424 of 15 March 2019 laying down ecodesign requirements for servers and data storage products pursuant to Directive 2009/125/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 617/2013

Executive Office of the President Office of Management and Budget (2019) Update to Data Center Optimization Initiative. Accessed via https://datacenters.cio.gov/policy/

Flucker S, Tozer R and Whitehead E (2018) Data centre sustainability–Beyond energy efficiency, Building Serv. Eng. Res. Technol., Vol. 39(2) 173–182, DOI: 10.1177/0143624417753022

Fulton S (2020) Just How Much Energy Will Edge Data Centers Consume?, Iceotope

Fryer E and Gilmore M (2017) Data centre standards map, 2017, techUK

Ganeshalingam M., Shehabi A, & Desroches, LB (2017), Shining a Light on Small Data Centers in the U.S, LBNL

GBI (2013) Green Building Index Assessment Criteria For NREB (Non-Residential Existing Building): data centre (version 1.0 | January 2013)

General Services Administration , Office of Governmentwide Policy, Office of Information, Integrity and Access (2016) Evidenced-Based Best Practices around Data Center Management: Lessons Learned from the Public and Private Sectors

Gosman N, Zeller MW, Rosemann ALP, and Pitis CD (2013) Energy at Risk: Opportunities for Applying Benchmark Energy Factors in the Industrial Sector, ACEEE industrial summer study, ACEEE Summer Study on Energy Efficiency in Industry

The Green Grid (2016) Driving Resource-Efficient IT, The Green Grid timeline v4

Greenpeace (2021) Green Cloud 2021 China's Internet Cloud Service Enterprise Renewable Energy Performance Ranking (in Chinese)

Greenpeace (2021a) Clean Cloud 2021: Tracking Renewable Energy Use in China's Tech Industry

Greenpeace East Asia and the North China Electric Power University (2019) Powering the Cloud: How China's Internet Industry Can Shift to Renewable Energy

Greenpeace USA (2017) Clicking Clean: Who is Winning the Race to Build A Green Internet?

Government Accountability Office (2021) Data Center Optimization GAO-21-212

Hintemann R and Hinterholzer S (2019) Energy consumption of data centers worldwide How will the Internet become green, ICT4S 2019 at: Lappeenranta, Finland

Hintemann R and Hinterholzer S (2020) DATA CENTRES IN EUROPE –OPPORTUNITIES FOR SUSTAINABLE DIGITALISATION Part 1 Borderstep Institute. For Eco – association of the internet industry

Hoffman IM, Greenberg S, Murrell J, and Newkirk A (2021) Tracking Data Center Efficiency: What PUE Can Tell Us and Where We Can Look To Better Understand Energy Performance, LBNL

Horner H and Azevedo I (2016) Power usage effectiveness in data centers: Overloaded and underachieving, The Electricity Journal, DOI

Huang R and Masanet E (2017) Chapter 20: Data Center IT Efficiency Measures Evaluation Protocol. The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures, NREL

Imboden K (2021) Data Center Global Market Comparison, Cushman & Wakefield

Indian Green Building Council (2016), IGBC Green Data Center Rating System Pilot Version, Abridged Reference Guide

ISO/IEC 30134-2 (2016) Information technology — Data centres — Key performance indicators —Part 2: Power usage effectiveness (PUE)

ITU (International Telecommunications Union) (2019), Data centre infrastructure management system based on big data and artificial intelligence technology, Recommendation ITU-T L.1305

Izadi Moud H, Kibert CJ, Flood I, Hakim H, and Shojaei A (2018) Greening Data Centers: Beyond LEED Version 4, Construction Research Congress 2018

Japan Data Center Council (2011) Outline of Data Center Facility Standard

JLL (2021) 2020 Year-End Data Center Outlook, A review of the industry's latest trends and what to expect in 2021

JRC (2021a) Code of Conduct on Energy Efficiency of AC Uninterruptible Power Systems (UPS) Version 2.0, DOI:10.2760/336458

JRC (2021b) European Code of Conduct on Data Centre Energy Efficiency Introductory guide for all applicants

Kamiya G and Kvarnström O (2019) Data centres and energy – from global headlines to local headaches? IEA

Koomey JG, Berard S, Sanchez M, Wong H (2011) Implications of Historical Trends in the Electrical Efficiency of Computing, IEEE Annals of the History of Computing, Volume 33, Number 3, DOI: 10.1109/MAHC.2010.28

Lawrence A (2021) Annual outage analysis 2021, UI Intelligence report 46, Uptime Institute

Le, D. V., Liu, Y., Wang, R., & Tan, R. (2020). Tropical data centre proof-of-concept, Nanyang Technological University

Lindsay S, Cavanagh K and Lovasz T (2021) Data Centres and the Energy Sector. CSIRO National Energy Analytics Research (NEAR) Program, Australia.

Linux Foundation (2020) White Paper: Sharpening the Edge: Overview of the LF Edge Taxonomy and Framework

Linux Foundation (2021) State of the Edge 2021 A Market and Ecosystem Report for Edge Computing

Mansoor A, May-Ostendorp P, Fortenbery B, Calwell C, Vairamohan B, Rasmussen R, Geist T, McIlvoy D, Boehlke J (2018) Generalized Test Protocol for Calculating the Energy Efficiency of Internal Ac-Dc and Dc-Dc Power Supplies, Revision 6.7.1, EPRI CLEAResult

Masanet E, Shehabi A, Lei N, Smith S, and Koomey J (2020) Recalibrating global data center energy-use estimates, Science Vol 367 Issue 6481, DOI: 10.1126/science.aba3758

McCarthy D (2020) AWS at the Edge: A Cloud Without Boundaries, International Data Corporation Accessed via https://d1.awsstatic.com/IoT/IDC-AWS-at-the-Edge-White-Paper.pdf

Mytton D (2021) Data centre water consumption, npj Clean Water

Munn L (2020) Staying at the Edge of Privacy: Edge Computing and Impersonal Extraction, Media and Communication, Volume 8, Issue 2, Pages 270–279

NABERS (2014) NABERS Energy for data centres, Rules for collecting and using data, Office of Environment and Heritage NSW

NABERS (2020) NABERS fact sheet data centres, Office of Environment and Heritage NSW

Netherlands Enterprise Agency (2020) Obligation to inform energy saving recognized measures implemented (Erkende Maatregelenlijsten energiebesparing) Industry 06 - Commercial Data Centers _(Bedrijfstak 06 - Commerciële datacenters)

Newmark R, Winkler K, (2017) ICT Capacity and Utilization Metrics, White Paper 72, The Green Grid

Norwegian Ministry of Trade, Industry and Fisheries (2018) Powered by Nature - Norway as a data centre nation – strategy

NSF International (2019) NSF/ANSI 426 – 2019, Environmental Leadership and Corporate Social Responsibility Assessment of Servers

OpenNebula (2021) OpenNebula's Approach to Edge Computing

Patterson M (Editor), Tschudi W, Vangeet O, Cooley J, and Azevedo D (Contributors) (2010) ERE: a metric for measuring the benefit of reuse energy from a data center, The Green Grid

Patterson M (Editor), Azevedo D, Belady C, Pouchet J (Contributors) (2011) Water Usage Effectiveness (WUE): A Green Grid Data Center Sustainability Metric, The Green Grid

Pope A (2021) Decoding the Edge: A Systematic Approach to Edge Deployments, DCD edge supplement

Pope D (2021) The 3 W's of Immersion cooling: what, why & when, Submer

Radovanovic A, Koningstein R, Schneider I, Chen B, Duarte A, Roy B, Xiao D, Haridasan M, Hung P, Care N, Talukdar S, Mullen E, Smith K, Cottman ME, and Cirne W (2021) Carbon-Aware Computing for Datacenters, arXiv:2106.11750

Raje S, Maan H, Ganguly S, Singh T, Jayaram N, Ghatikar G, Greenberg S, Kumar S, and Sartor D (2015) Data Center Energy Efficiency Standards in India: Preliminary Findings from Global Practices, e-Energy ‘15: Proceedings of the 2015 ACM Sixth International Conference on Future Energy Systems, DOI: 10.1145/2768510

Ranaweera P, Jurcut AD, Liyanage M (2019) Realizing Multi-Access Edge Computing Feasibility: Security Perspective, IEEE Conference on Standards for Communications and Networking, DOI

Reddy VD, Setz B, Subrahmanya, G, Rao VRK, Gangadharan G R, and Aiello M (2017) Metrics for Sustainable Data Centers, IEEE Transactions on Sustainable Computing

Salim M (2020) How Green Standards are Changing Data Centre Design and Operations, Synthesis.

Sartor D, Van Geet O, Martinez D (2019) New Horizons: Getting (Back) to Liquid Cooling, 7 × 24 Exchange International Fall Conference Phoenix, AZ

Schödwell B, Erek K and Zarnekow R (2013) Data Center Green Performance Measurement: State of the Art and Open Research Challenges, Nineteenth Americas Conference on Information Systems, Chicago, Illinois

Shally, Kumar Sharma S, Kumar S (2019) Measuring Energy Efficiency of Cloud Datacenters, International Journal of Recent Technology and Engineering

Shapiro S (2019) Data Center Design: Which Standards to Follow?, Afcom

Shehabi A, Smith SJ, Masanet E and Koomey J (2018) Data center growth in the United States: decoupling the demand for services from electricity use, Environ. Res. Lett. 13 DOI

Shi W, Pallis G, and Xu Z (2019) Edge Computing; Scanning the issue, Proceedings of the IEEE, Vol. 107, No. 8, DOI: 10.1109/JPROC.2019.2928287

Siddik MAB, Shehabi A and Marston L (2021) The environmental footprint of data centers in the United States, Environ. Res. Lett. 16 (2021) 064017

Singh H (2011) Data Center Maturity Model, The Green Grid

SNIA (2020) SNIA Emerald™ Power Efficiency Measurement Specification, Version 4.0.0

State of NSW and Office of Environment and Heritage (2019), NSW Government Resource Efficiency Policy

STL (2020) Edge computing insights

Swiss Datacenter Efficiency Association (2020) KPI definition

techUK (2017) (Climate Change Agreements for Data Centres) Target Period Two: Report on Findings

techUK (2020) The UK Data Centre Sector – sector overview

techUK Data Centres Technical Committee (2017) Briefing Note: Measuring Data Centre Performance

Tempest H (2020) Data Centres: A guide to sustainable energy procurement, WePower

Turner W Pitt, Klesner K and Orr R (2014) Implementing Data Center Cooling Best Practices, Uptime Institute

UN (2019) The United Nations World Water Development Report 2019

Uptime Institute (2021) Tier Classification System

van de Voort T, Zavrel V, Torrens Galdiz I and Hensen J (2017a) Analysis of performance metrics for data center efficiency – should the Power Utilization Effectiveness PUE still be used as the main indicator? (Part 1), REHVA

van de Voort T, Zavrel V, Torrens Galdiz I and Hensen J (2017b) Analysis of performance metrics for data center efficiency – should the Power Utilization Effectiveness PUE still be used as the main indicator? (Part 2), REHVA

Villars R and Goodison D (2020) Cloud And Edge Computing Are Key To 'Next Normal': IDC, CRN

Wang D, Bulut Y and Seymour M (2019) Infrastructure Usage Effectiveness, Green Gauge Standard Committee

Wegner M, Turnell H, Davies G, Revesz A, and Maidment G (2021) Investigation of opportunities for utilising waste heat for district heating networks in cities, CIBSE ASHRAE Technical Symposium, CIBSE Virtual Event, 13-14 July 2021.

Whitney J and Delforge P (2014) Data Center Efficiency Assessment, Scaling Up Energy Efficiency Across, the Data Center Industry: Evaluating Key Drivers and Barriers, NRDC and Anthesis

Wu A, Ryan P and Smith T (2019) Intelligent Efficiency For Data Centres & Wide Area Networks, IEA 4E Electronic Devices and Networks Annex

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