Cloud Computing in Europe

Appendix 14

Green ICT

30th October 2020

h-cloud.eu

Title	Cloud Computing in Europe: Green ICT
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Version	0.7
Date	30th October
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Important Notice: Working Document

This briefing is an annex to the Green Paper v 1.0. The Green Paper is an outcome of the H-CLOUD project, a Coordination and Support Action that has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement n. 871920.

CONTENTS

1 INTRODUCTION

Information and Communication Technologies alone are estimated to account for up to 8% of world power consumption[1], ICT energy efficiency, especially in Cloud Computing, is important for the economy, energy conservation, and environmental responsibility. However, the Cloud is often thought of in abstract terms but there is a concrete reality underpinning this. Cloud servers are housed in large remote data centres where they provide services to end users. The end user, therefore, needs a local client machine in order to consume the service. A network is required between these two end-points to join them together. It is not only the data centre that consumes energy but also the network devices and the end-user devices as well. We will consider all three elements here. Moreover, in the context of Cloud computing, Green Cloud can be thought of as a super set of Green ICT. This is because Cloud computing is a service model for compute, not only a set of technologies. For this reason, data types and usage fall into scope, as does the manner in which they are created and consumed. While these final two topics may seem completely unrelated to Green ICT, they introduce important considerations into the debate.

In this briefing paper, we begin with a definition of Green ICT and then briefly consider lifecycle issues associated with the hardware and the energy consumption of that hardware when it is in use. The main focus of the paper is on the data centre itself but we also consider the network elements and end-user devices as well. Media and the data volumes that underpin them are also considered, as are end-user behaviours, data physics and potential new materials.

[1] https://www.vertatique.com/ict-10-global-energy-consumption

2 DEFINITION OF GREEN CLOUD COMPUTING

2.1 Background

No good definitions of 'Green Cloud' could be found on-line. A decade ago, the term "Green Cloud" referred to the Cloud in general, pointing to the potential environmental benefits that ICT services delivered over the Internet could offer society.

However, the word "Green" was then defined very loosely, with Pike Research asserting, in 2011, that the comprehensive adoption of Cloud computing may lead to a 38% reduction in worldwide data centre energy expenditures. Since then, reasoning over the true environmental impact of data centres has matured and become more sophisticated. In other words, the green credentials of Cloud computing are currently being seriously debated.

If we are to continued using the term and to use the same model, we need to define more tightly what Green Cloud might mean, now and in the future.

As "Green" is the most difficult word in the term 'Green Cloud' we consider its fit in relation to the EU Green Deal[2]. The Green Deal has 'investing in environmentally-friendly technologies' as one of the headline actions and this maps onto 'The Circular Economy' in the related Action Plan. 'The Circular Economy' line in the Action Plan refers to 'a sustainable products initiative', which aims to focus on a small number of problematic and resource intensive sectors, one of which is electronics. The Circular Economy is a concept designed to protect the environment from the effects of mineral and other resource exploitation, mitigating the damage to be caused by current activities and remediating the damage already caused.

Also mentioned in the Green Deal, but at a higher level in relation to policy design, is the issue of human health. The health issue is not directly explored in relation to electronics in the Circular Economy of 'The Green Deal' but the Global e-Waste Statistics Partnership[3] considers direct and indirect human health issues associated with electronic equipment in relation to mineral/resource extraction hazards: manufacturing, operational and transport hazards; and recycling/scrap hazards.

2.2 Towards a tighter definition of Green Cloud

Green Cloud is a remotely hosted ICT remote server-based service delivery model which uses the internet for service access, and is directly & indirectly environmentally & health neutral in all aspects of its operation.

1. Green Cloud services are deployed through devices and installations that are environmentally and health neutral in construction.

[2] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[3] Founded in 2017 by the International Telecommunication Union (ITU), the United Nations University (UNU), and the International Solid Waste Association (ISWA). Its aim is to collect data that will inform policy makers in relation to achieving Sustainable Development Goals.

2. Green Cloud devices and installations are made from minerals and other resources that are environmentally and health neutral:
   - in terms of their extraction.
   - during their recycling, recovery of reusable elements, and disposal.

This definition, therefore, grounds the semantics of "Green Cloud' in the existing policy developments underpinning 'The Green Deal' (and other global policy activities related to health). Both activities are already underway, with the Green Deal targeting 2050 as the end-point for its carbon neutrality and environmental protections to be fully satisfied. This means that the grounding mechanism of the new definition will change over time and, correspondingly, compliance with the definition will change as well. This leads to a dynamic definition that requires those entities wishing to describe themselves as offering 'Green Cloud' services to make ever bolder steps to keep up with Green Deal progress… and to contribute to its successful conclusion.

3 LIFECYCLE

The first version of this discussion paper looked at Green ICT from the lifecycle perspective. This version contains a comprehensive breakdown of lifecycle issues. See H-Cloud_App13_GreenICT_Lifecycle_View.

4 THE DATA CENTRE

Cloud computing has its pros and cons. There is much evidence that Cloud computing is better for the environment than the similar capability offered through conventional means[4][5]. However, in 2012 data centres use around 30 gigawatts of electricity each and they can waste most of that energy (up to 90 percent of it)[6]. With that massive amount of power going to waste, are they doing more harm than they are worth?

Cloud is creating fewer but vastly larger data centres. Smaller corporate data centres are relatively easy to optimise, the large Cloud data centres are not because they have to respond to the whole range of unknown business requirements, not merely those of one business, which are known[7]. However, it was recognised as far back as 2102, that the energy use in data centres was growing 12 times faster than worldwide energy use[8]. Since then, some improvements to Data Centre (DC) energy efficiency have been achieved; however, this has mainly been achieved in the wider context of carbon neutrality and this path has been undertaken by many of the current hyper-scalers. Moreover, these advances have been achieved mainly through offsetting techniques and consuming renewable energy, not through direct improvement in the design and operation of data centres.

Offsetting techniques have also been a target of critics, who argue whether they are helpful, or counterproductive, in the fight against climate change.

Assertions

- Green ICT covers many areas. Cloud energy efficiency is one of them.
- Cloud Computing services run in Data Centres but they are delivered through networks to end-users who consume them on local devices.
- There is a strong relationship between energy consumption, greenhouse gas emission, operational costs for the data centre.
- Cloud providers aim to maximise energy efficiency per billed task but are not motivated to reduce user infrastructure inefficiencies, i.e. the deployment of an unused cluster.

The current focus on DC energy efficiency is on hardware, notably through the Open Compute Project[9] but operations and networking can also play its part.

Green Cloud energy efficiency can be improved through addressing several aspects.

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4 Berl, A et al (2009) Energy-Efficient Cloud Computing, in The Computer Journal, Vol 53, Iss 7, PP 1045-1051. Print ISSN 0010-4620. Available online at https://doi.org/10.1093/comjnl/bxp080

5 Lohr, S (2020) Cloud Computing Is Not the Energy Hog That Had Been Feared. NY Times. Available online at https://www.nytimes.com/2020/02/27/technology/cloud-computing-energy-usage.html Accessed 03/06/2020

6 Andrae, Anders. (2017). Total Consumer Power Consumption Forecast. Nordic Digital Business Summit, Helsinki

https://www.researchgate.net/publication/320225452_Total_Consumer_Power_Consumption_Forecast

7 Costenaro, David and Duer, Anthony (2012) The Megawatts behind Your Megabytes: Going from Data-Center to Desktop. ACEEE Summer Study on Energy Efficiency in Buildings

8 Lechner, 2009 from “Greening through IT. Information technology for environmental sustainability” Bill Tomlinson 2010

9 https://www.opencompute.org/about

Hardware	Server	Storage	Networking	
Infrastructure	Power	Cooling	Physical Space	
Software Infrastructure	Operative System	Virtualization	Microservices	Server-less computing
Software	Energy aware scheduling	Consolidation of computing	Data Sedimentation	Data, traffic and processing reduction
Process	E-Waste Recycling	Energy Sources	Business Processes	Automation & Machine Learning

4.1 Hardware

4.1.1 Data Centre energy supply and renewable power sources

In the Green ICT context, DC Operations will need to be able to match the demand of its machines with the characteristics of its energy supply. As such real-time Demand - Response Management systems will be required. Matching DC energy needs with the supplier's ability to meet them at any time is difficult, especially when the supplier is fed with intermittent and transient renewable sources. Notably, supply voltages should be designed to match system demands in order to ensure that energy losses are minimised[10]. This will require a variable voltage supply managed by a dynamic voltage management system which should be capable of live monitoring energy demands in real-time. While renewable energy sources are desirable in the Green ICT context, this kind of variability is made even more difficult to manage if the energy supplier is using renewable power sources, the outputs of which are inherently variable in nature. In this case, the **energy supplier will need to be able to deploy variable energy management systems** in the upstream as well as downstream side of its network[11].

4.1.2 Energy-efficient hardware

A 2007 study[12] evaluated that the power consumed by an idle server can be 50% of the server's peak power. Modern servers offer a wider range of power states to help mitigate the issue, but the best option to save power is still to **switch servers to the lower power states when they are not in use**. This can be obtained with a combination of hardware and software, coupling strategies like load balancing, or VM migration to power-aware hardware. In the software section, we will explore in more detail.

[10] Clancy, H. (2012) Four ways providers can improve cloud computing energy efficiency. TechTarget. Available online at https://searchnetworking.techtarget.com/tip/Four-ways-providers-can-improve-cloud-computing-energy-efficiency Accessed 03/06/2020

[11] Eaton Corp. (2019) Power Distribution Systems: Design Guide SA081002EN. Available on line from https://www.eaton.com/us/en-us.html

[12] L. Barroso and U. Holzle, (2007) "The case for energy-proportional computing," Computer Journal, vol. 40, no. 12, pp. 33–37

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4.2 Infrastructure

4.2.1 Hardware and software uniformity

Hyperscale cloud providers take advantage of their scale economy, not only by contracting the lowest possible price for the hardware but also by optimising the cost of design and implementation of new Data Centres, to enable rapid expansion. A key role in this optimisation is a modular approach to the design and operation of a DC, which ideally represents an instance of a replicated and well-known hardware cell.

That enables the use of the same tools with minimal configurations, centralised management, easier migration, advanced recovery, and fault tolerance strategies.

The cost of maintenance, upgrade and optimisation of hardware plays a key role, not only for the hardware itself but also for the human component. Skilled professionals are necessary figures, this can be expensive and the DCs are often understaffed in the public and scientific cases, for this reason, it is crucial that their efforts are as effective as possible. From this point of view, the adoption of shared DC design solutions is desirable [13][14] along with the reduction of heterogeneity of hardware and software.

Consider specially designed hardware to maximise performance per watt

4.2.2 Infrastructural optimisation

Reusing exhausted environmental conditioning products (not only air but also water in modern applications) to heat or cool the administrative/domestic areas of a DC operation is more energy efficient than venting it externally and requires relatively simple changes to the existing DC infrastructure.

Managers should consider the cooling requirements of hardware in the acquisition process. The energy costs of running the equipment as well as those associated with keeping it cool need to be taken into account. DC cooling is where most gains in energy saving can be found: between 30% to 40%.

Design the physical aspects of the DC to accommodate the hot and cold areas already mentioned.

Approach the DC architectural design following a thin client approach, with its internal services spread over its own hardware to ensure that only those internal services required by an external service are placed under internal load.

Job scheduling and, therefore, energy-efficiency scheduling are recognised as an NP-hard problem across industry generally. The ICT industry is no exception to this. **Swarm intelligence and evolutionary algorithms have been explored as a possible solution. This remains an open research area and needs to continue to be funded if the Greening of ICT is to be achieved.**

Storage architecture should be tiered to accommodate user needs without compromising QoS but yielding reductions in energy consumption. For example, data archives and low i/o jobs should be scheduled to run on slow, low energy machines, not in high performance machines.

Correlate the deployment of DC hardware and DC services with the needs of user applications. A single specification deployed uniformly across a DC infrastructure will likely not meet the performance needs of a client wishing to run a data mining application over a large data lake, while resulting in a client with only word processing needs being vastly over-charged.

Another relevant topic is the localisation of data, and its distance from the computing elements, for avoiding inefficient network transmission. Traditional caching techniques have been put in place, while

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[13] Converting DCs in Energy Flexibility Ecosystems (CATALYST) https://cordis.europa.eu/project/id/768739

[14] Prototyping the most energy and cost-efficient data center in the world: The Boden Type Data Center https://cordis.europa.eu/project/id/768875

another emerging paradigm is to move the computation instead of data when that is possible (and convenient) as is the case in federated Clouds.

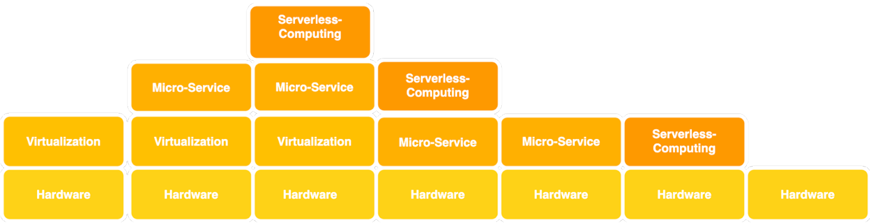
4.2.3 The energy impact of Networking

Recent reports claiming an increase in DC energy efficiency show that many improvements to energy efficiency are already deployed and are in use, especially by the hyperscalers, but that many smaller DC service providers still lag behind the adoption curve. However, such reports do not take into account the fact that for (public) Cloud users, there exists a fundamental need for them to be able to connect to the Cloud service running in a DC. The Internet satisfies this need. How much does the energy required to run the internet cost? How can it be reduced? This criticism applies also to the previous DC energy efficiency discussions, notably, many of these approaches could be applied to the Internet. Is there the will to do this?

4.3 Software infrastructure

The offer of different Cloud Providers is in constant expansion and evolution, some of them are in the position of providing not only a complete set of services for IaaS, PaaS, SaaS and FaaS, but also multiple alternatives in the same space from their own catalogue. In such a diversified scenario it is still possible to identify some major trends and paradigms that have a recognizable impact on energy efficiency.

Newer paradigms aim to be more efficient and therefore their adoption is in general suggested. Reality, however, is never too simple and it is common that the following models will be offered as a combination of some of the others as per picture. Another aspect to keep into consideration is that migration to new paradigms is expensive and could produce unwanted duplication and tension between systems, when not carried on organically.



It is difficult to corroborate these statements with publication or research, because of the youth of these technologies. One of the most influential papers in recent years[15] describes the results obtained by Google with their own internal We Borg orchestrator, which can be considered the proprietary version of the open source project Kubernetes (or its step-father), while very recently in 2020, they released another relevant paper about their vertical and horizontal autoscaler Autopilot[16], which uses machine

[15] Verma A, Pedrosa L, Korupolu M, Oppenheimer , Tune E, Wilkes J (2015) Large-scale cluster management at Google with Borg, Google Inc.

[16] Findeisen P, Świderski J, Zych P (2020) Autopilot: workload autoscaling at Google. Krzysztof Rzadca (Google & University of Warsaw, Poland), Google Inc

learning algorithms applied to historical data "to configure resources automatically, adjusting both the number of concurrent tasks in a job (horizontal scaling) and the CPU/memory limits for individual tasks (vertical scaling)."

Once we take into account that Google's Data Centres are amongst the best performers of the entire industry in terms of PUE ("Based on industry benchmarks of PUE, Google's data centres are amongst the most efficient when it comes to overhead energy consumption with a PUE of 1.11 compared to the industry benchmark of 1.67[17]") , we understand that the relevance of these publications goes beyond the computation model and proprietary systems, but we can safely assume that it should have a strong indirect influence also in Energetic Efficiency, and we should probably try to learn some lessons from them, in the choice of the most efficient software infrastructure stack.

4.3.1 Virtualisation

The benefits of virtualisation have been underlined in research, allowing sharing of resources, reduction of consumption from idle services, and the migration from multiple physical servers to virtual machines packed in fewer and usually more energy-efficient servers. Careful use of virtual images can also improve speed and agility: enabling off-line installation, updates, and testing, can save hours of computation in case of multiple nodes deployments, at the same time allowing the use of advanced recovery solutions.

Internally, the utilisation of DC resources should be improved. One way to achieve this is to deploy virtualisation technologies[18]. These technologies can be used to provide service mobility through the DC infrastructure to physically locate a "hot" service in a cool(er) part of the DC and vice versa. It can also be used to reduce hardware over-capacity, through dynamic on-switching based on actual live demand. DC collaboration (DCs working together matches a Federation Use Case?) can also be used to reduce hardware over-capacity, especially when teamed with virtualised mobility techniques.

Software defined, virtual networking techniques can also help reduce DC energy consumption through radically reducing the amount of dedicated hardware and software required to run a conventional network. All such devices require energy, so reducing their numbers de facto reduces the DC energy demand. In fact, the internal SDN can run in the DC's own Cloud servers[19].

4.3.2 Micro-services

Microservices is a paradigm that recently came to the attention of both industry and research.

From the advent of Docker and Kubernetes, microservices have seen a surge in their adoption, reflecting the benefits the industry has recognized. In terms of energy efficiency, containers tend to require fewer resources compared to virtualisation. This is because the Operating System is shared among all the containers running on a single host, and the benefit is so dramatic, that it continues to be true even when containers are provided on top of Virtual Machines. A secondary benefit is related to the data size of the containers, which tends to be much smaller than VM, which translates to saving disk space as well with computation and network times and, therefore, also in energy consumption.

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[17] Google's Hyperscale Data Centres And Infrastructure Ecosystem In Europe: Economic impact study https://www.copenhageneconomics.com/dyn/resources/Publication/publicationPDF/0/500/1569061077/copenhagen-economics-google-european-dcs-infrastructures-impact-study_september2019.pdf

[18] Tesfatsion, SK (2018) Energy-efficient Cloud Computing: Autonomic Resource Provisioning for Datacenters. ISBN 978-91-7601-862-0. Umea University

[19] It is worth noting that an SDN would likely bring with it an additional dimension to security and privacy.

4.3.3 Serverless computing (Functions-as-a-Service)

Serverless computing is a computing model where the cloud provider is responsible for executing directly the instructions of the customer of the code, by dynamically allocating the resources, is promoted as being economically efficient, and represents the pinnacle of Cloud Computing. It enhances the concept of Cloud Computing, delegating both hardware and software infrastructure to Cloud providers, doing so it provides extreme agility for the developers at cost any possible control over the infrastructure. For this reason, it requires maximum trust in the cloud provider not only for the purpose of optimization but also for security, making strict legal agreements necessary.

Energy efficiency has yet to be demonstrated and should be evaluated taking into account all of the components involved. However, this is a novel activity in this area and there is not yet any literature about it; similarly, there is no de facto standard defined in the field of server-less frameworks.

4.4 Software

4.4.1 Consolidation of computing

Interesting reading about possible approaches to achieve energy savings is[20], which discusses: workload prediction, VM placement and workload consolidation, and resource overcommitment. It concludes with: "great energy savings can be achieved by **turning more servers into lower power states and by increasing the utilization of the already active ones**."

4.4.2 Resource reclamation

In the specific case of the scientific and medical environment which often deals with a large number of low priority and scheduled jobs, it could also be interesting to investigate intro the usage of these workloads in compensation factor for the optimisation of consolidation techniques. In 2015 Google demonstrated [8] that a similar approach can be quite effective to avoid wasting allocated resources that are not currently being consumed. They estimate how many resources a task will use and reclaim the rest for work that can tolerate lower-quality resources, such as batch jobs (non-production jobs).

4.4.3 Scheduling prediction

It is important to understand that the relevance of correct forecasting in the scheduling area is more important for workloads that are associated with bigger penalties for the migration[21]. That explains the success in the orchestrator for containers compared with the once for virtual machine, while few seconds of rescheduling penalty for a wrong prediction can be justified, it is much less acceptable to waste computing minutes.

[20] Dabbagh M, Hamdaoui B, Guizani M and Rayes A, "Towards Energy-Efficient Cloud Computing: Prediction, Consolidation, and Overcommitment" in *IEEE Network*, vol. 29, no. 2, pp. 56-61, March-April 2015, doi: 10.1109/MNET.2015.7064904.

[21] Gao, K., Huang, Y., Sadollah, A. et al. (2019) A review of energy-efficient scheduling in intelligent production systems. Complex Intell. Syst. Springer. https://doi.org/10.1007/s40747-019-00122-6

4.4.4 Data Sedimentation and Storage hierarchy

Employing hierarchical types of storage, based on the type of data, can provide a huge impact in energy savings for large datasets. AWS Glacier and the usage of tape in the scientific community are two examples of solutions that can be adopted for long term preservation and infrequent access data. Approaches that automatically consolidate long term unused data over servers that can be shut down whenever the server needs to be maintained not only by infrastructure that have keep track of the access and provided the freeze-unfreeze mechanism, but also by the end user software that has to take into account an longer delay in the provision of the data.

4.4.5 Data, traffic and processing reduction

The size of data have a direct impact on the amount of energy required to process and store data. Several strategies can be used to minimise the space required by data, while still ensuring, availability, and integrity. **Algorithms for Data compression & Data deduplication can be extremely efficient in specific domains**.

4.5 Process

4.5.1 E-Waste Recycling, Energy Sources & Business

A set of choices which seriously impact energy efficiency can be made outside of the technological implementation of Cloud Computing. These particular choices, concerning the fields of business and strategy decisions. For example we can think about the implementation of an E-Waste Recycling plan, the decision about the Energy Sources used by the Data Centre or even the timing and prioritization of the implementation plans.

In the case of federations or a similar environment, with a pay upfront - free to use model, the introduction of benefits/price concepts, could mitigate the use of inefficient sites, or make more attractive the usage of efficient computing models like **low priority computation and scheduled job**s.

4.5.2 Automation & Machine learning

Automation in Cloud Computing can be implemented with the use of different technologies and tools, it enables IT teams to create, modify and remove resources automatically, that can vastly increase efficiency, improving velocity and reliability.

More broadly it can be intended as a process that should include not only the hardware and software, but also the development process, management of emergency and failures, policy enforcement and in general all the lifecycle of the use of Cloud. Some key enablers for making that possible are: the adoption of Site Reliability Engineering (SRE)-DevOps techniques, infrastructure as code, workload management, application development and testing, closed-loop systems, introduction of AI in the management pipeline for error recovery, and prevention.

From the paper already cited[8], Google studied and implemented machine learning algorithms applied to historical data, demonstrating that “Autoscaling is crucial for cloud efficiency, reliability, and toil reduction. Manually-set limits not only waste resources (the average limits are too high) but also lead to frequent limit violations as load increases, or when new versions of services are rolled out”.

4.6 KPIs and Standards

There are few, often primitive, KPIs and standards in the Green ICT domain; critically, they all sit in the data centre component of Cloud computing. The most common of these KPIs is hardly fit for purpose and there are many debates about approaches to its use and its continuing suitability. Furthermore, it is not safe to assume that just because a metric is seen as questionably suitable it will be discarded. The original metric, PUE, still finds favour because it suits the data centre operators, in that they find it easy to manipulate. Since PUE was developed, many other metrics have been identified and deployed, they all measure different aspects of a data centre operations, often arranged in combination. Only one comprehensive standard associated with data centre operations has been discovered in this preliminary review.

Clearly, the metrics and standard mentioned above are available for use by anyone. Many of the hyper-scalers employ their own metrics and standards but these are protected as industrial secrets as they compete with each other to give the most favourable impression regarding their efforts to achieve green credentials, with carbon offsetting as the primary mechanism allowing hyper-scalers to claim carbon neutrality.

While the data centres host the servers that deliver Cloud services, there are other ICT devices that are essential to the consumption of those same services: Data Centres, Core Network Devices and Access Network Devices.

4.6.1 Data Centre Metrics

The **Power Usage Effectiveness (PUE)** is the original data centre efficiency metric and has been formalised as - ISO/IEC 30134-2:2016. It compares energy requirements of computing equipment with all other equipment in the data centre. However, its appropriateness is strongly contested and debated, PUE is 'limited' to the energy used to keep the data centre running and the IT load of.

Data Centre Infrastructure Efficiency (DCiE) is the inverse of PUE and suffers from the same problems.

Energy Re-use Factor (ERF) measures, how well a data centre deals with its waste (heat, energy, etc.)

Carbon Usage Effectiveness (CUE) includes the direct emissions of the data centre, primarily from backup power generators, and the emissions of the power utility, the emissions of the mining and manufacturing operations that supply fuel and equipment to the power utility.

Water Usage Effectiveness (WUE) determines the amount of water used by the facility and the efficiency of that usage in IT operations.

Data Centre Productivity (DCP) considers the amount of useful work that a data centre produces in relation to the amount of a consumable resource that it employs to produce this work.

Data Centre Energy Productivity (DCeP) updates PUE but takes a more holistic approach, quantifying the 'useful work' that a data centre produces based on the amount of energy it consumes.

The Green Energy Coefficient (GEC) measures how much of a facility's energy use is sourced from green source (wind, solar, geothermal plants, etc.).

Digital Service Efficiency (DSE) has been developed by eBay as a unified data centre productivity metric. It is more of a methodology that enables managers to correlate the costs of running a data centre with the profits generated by the business. As such it is neither a metric (or standard), nor is it related to environmental / energy efficiency issues.

4.6.2 Data Centre Standards

PUE, CUE, WUE, DCP, DCeP and ERF are actually metrics rather than standards. **ASHRAE**[22] **90.4-2016**, on the other hand, is a comprehensive standard against which a broad range of data centre efficiencies can be measured. Here PUE is replaced by combining Mechanical Load Component (MLC) and Electrical Load Calculation (ELC).

[22] American Society of Heating, Refrigerating and Air-Conditioning Engineers

5 CANDIDATE DATA CENTRE METRICS AND STANDARDS FOR DEU/CEF

No obvious candidates exist; however, a combination of PUE, CUE and WUE seem to be used together very often by data centre owners. This combination can also be used within the ASHRAE 90.4-2016 standard, if it is determined to be a suitable basis, and if a fully comprehensive approach is desired.

It is not correct to say that standards relating to Energy Efficiency in Data Centres do not exist but they are either being brought in from related industrial sector (industrial climate control), are very immature, or are formed through clustering a number of KPIs. The EC has published guidelines[23] but these are more informal documents than a true standard.

Energy Efficiency KPIs begin at the Construction Industry level, where factors are taken into account when constructing any building, including DCs. The Siemens white paper discusses these in detail[24].

DC-relevant KPIs are not standardised and do not specifically focus on Energy Efficiency. They focus on the wider aspects of efficiency and safety. Those published by the Data Center Frontier[25] form a useful starting point:

- Capacity by Key Data Center Resource
  - Space, Power, Cooling, and Power/Network Port Connections.
- Data Centre Energy Cost.
- Change Requests by User, Stage, and Type.
- Available Cabinet and Floor Space Remaining.
- Cabinets with Most Free Data Ports and Power Ports.
- Peak Load Per Cabinet Over Last 30 Days.
- Cabinet Power Failover Redundancy Compliance.
- Power Usage Effectiveness (PUE).
- Percentage of Cabinets Compliant with ASHRAE Standards.
- Hot Spots Occurrence and Duration.

Moreover, standard metrics for comparing DC have been proven to be difficult to define because of the differentiations in DCs and their network. For this reason, several Key Performance Indicators (KPI) have been identified to cover issues associated with operational tracking and management of efficiency over time.

The landscape of metrics available is quite broad, a large number of stakeholders, including standards and industry bodies, have developed a range of targets, recommendation, guidelines and metrics. These metrics continue to be developed and increased in number, but they are often interlinked and partially overlapping.

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23 Acton M, et al (2018) 2018 Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency v 9.1.0. JRC Science Hub https://ec.europa.eu/jrc/en/publication/2018-best-practice-guidelines-eu-code-conduct-data-centre-energy-efficiency-version-910

24 Siemens. (2014) White Paper: Managing Energy Using Key Performance Indicators. Downloaded from the Google archive at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwi1tcypp-bpAhXah1wKHVrnDl0QFjAIegQIChAB&url=https%3A%2F%2Fassets.new.siemens.com%2Fsiemens%2Fassets%2Fapi%2Fuuid%3Accb07906-df33-4db0-b782-6fc7f2d346f5%2Fversion%3A1560794068%2Fbt-cc-managing-energy-using-kpis-whitepaper-en.pdf&usg=AOvVaw1UcpdfUtfGjNd0xYDal_ts

25 https://datacenterfrontier.com

For a detailed discussion refer to Intelligent Efficiency for Data Centres & Wide Area Networks[26] and Annex A for a list of standards. There is also much useful information available from reliable industry and governmental bodies that that seek to promote and improve decision-making throughout the data centre operational cycle[27][28][29].

[26] Intelligent Efficiency for Data Centres & Wide Area Networks. IEA-4E EDNA May 2019 https://www.iea-4e.org/document/428/intelligent-efficiency-for-data-centres-and-wide-area-networks

[27] https://www.upsite.com/blog/introduction-to-international-data-center-standards-part-1/

[28] https://www.upsite.com/blog/introduction-to-international-data-center-standards-part-2/

[29] https://e3p.jrc.ec.europa.eu/communities/data-centres-code-conduct

6 NETWORK DEVICE ISSUES

6.1 Core Network

All Cloud data traverse the Internet core on its way to the user. No metrics can be found that are related to energy efficiency there. Nothing has yet been developed as a standard but there is acute awareness of the need for a reduction in energy consumption, and cross-industry initiatives are taking place to address this shortfall.

While the Internet's energy consumption is a fraction of that of the transportation industry, which accounts for 61 percent of all oil production[30], an estimate of the amount of electricity the Internet actually requires, showed that in 2011 it consumed 84 to 143 gigawatts; roughly 3.6 and 6.2 percent of all electricity worldwide[31]: not insignificant.

6.2 Access Network

Different parts of the Internet contribute to network power consumption as Internet access increases over time. Currently, the access network domain dominates the Internet's power consumption and, as access speeds grow, the core network routers will come to dominate power consumption. The power consumption of data centres and content distribution networks is dominated by the power consumption of data storage for material that is infrequently downloaded and by the transport of the data for material that is frequently downloaded[32]. A code of conduct has recently been published by the European Commission relating to increasing the energy efficiency of (domestic) access networks[33]. A recent regulation 1275/2008 (17/12/2008) which implements Directive 2005/32/EC for eco design requirements of standby and off-mode electric power consumption of electrical and electronic household and office equipment.

The two main areas requiring attention in the context of overall power consumption are the access networks (in particular the home terminal equipment) and the core network routers.

6.3 Network Edge

The summed energy requirement of several small devices (at the network edge) reveals that such devices consume more power than a single larger device of the same sum capacity. Energy losses during power distribution to several small devices is relatively inefficient, when once again, compared with a single larger device. The Internet of Things is about sensors and actuators and it relies on sub-

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[30] Glanz, James. "Power, Pollution and the Internet." The New York Times. Sept. 22, 2012. (Nov. 20, 2012) http://www.nytimes.com/2012/09/23/technology/data-centers-waste-vast-amounts-of-energy-belying-industry-image.html

[31] Raghavan, Barath and Ma, Justin. "The Energy and Emergy of the Internet." Hotnets '11. Nov. 14-15 2011. (Dec. 5, 2012) http://www.cs.berkeley.edu/~jtma/papers/emergy-hotnets2011.pdf

[32] Hinton, Kerry & Baliga, Jayant & Feng, Michael & Ayre, Robert & Tucker, Rodney. (2011). Power Consumption and Energy Efficiency in the Internet. Network, IEEE. 25. 6 - 12. 10.1109 MNET.2011.5730522.

[33] European Commission, "Code of Conduct on Power consumption of Broad-band Equipment," v. 7, 2019. https://e3p.jrc.ec.europa.eu/publications/eu-code-conduct-energy-consumption-broadband-equipment-version-7

optimal energy losses associated with Edge computing in order to function. Recent research into using naturally occurring organisms (plants, etc.) as sensors has demonstrated the practical utility of using features in the environment to monitor itself[34]. Maybe this is a partial solution to the energy sub-optimality at the network Edge? In future.

Overall, however, **reducing the need for the deployment of powered Edge sensors should be encouraged**

[34] Chatterjee, Shre & Das, Saptarshi & Maharatna, Koushik & Masi, Elisa & Santopolo, Luisa & Colzi, Ilaria & Mancuso, Stefano & Vitaletti, Andrea. (2017). Comparison of Decision Tree Based Classification Strategies to Detect External Chemical Stimuli from Raw and Filtered Plant Electrical Response. Sensors and Actuators B: Chemical. 249. 10.1016/j.snb.2017.04.071.

7 END-USER DEVICE CONSIDERATIONS

7.1 Behaviour

End-user devices are the last link in the Cloud computing experience. However, it has been demonstrated that a large contributor to total internet energy demand is can be attributed to devices not being well matched to the media they are processing. For example, if a low-resolution game is being played then there is no need for the end-user computer to be very powerful. Clearly, there are no metrics (beyond the simple frequency counter) or standards in this area. So, a behavioural change may be required (through training?) to achieve a benefit here. A possible solution may also be found in the area of processor technology, where a chip is designed that accommodates an advanced form of dynamic frequency scaling on the CPU that has not yet been developed.

7.2 Domestic Network Access Device KPIs and Standards

All Cloud data traverse access networks on their way to the user. Access networks are recognised as the domain where most energy is consumed.

Meeting the energy efficient ethernet standard (**IEEE 802.3az**) results in energy reductions of approximately 10%.

Energy Star is a program run by the U.S. Environmental Protection Agency and Department of Energy, meeting this standard sees up to 20% energy demand reductions when a compliant device is compared to a similar standard device.

The Advanced Configuration and Power Interface (***ACPI***) offers a technical API that allows router software to control router hardware, with a view to allowing operators to seek opportunities to reduce the energy demand of the device.

7.3 Recycling of Retired Devices

A right to repair has recently been brought in by the EU[35], this should extend the life of many devices far beyond what is possible now. However, we are starting from a very low baseline. A recent study showed that, collectively, UK citizens had approximately 527 million old devices in their homes, and each year 500 thousand metric tonnes of waste electricals are thrown away, hoarded, stolen or illegally exported. However, the same U.K. households could save $M463 if all these devices were recycled. Moreover, if people took the time to sell their unwanted devices, each household could generate around $776 in additional income[36].

[35] https://www.bbc.co.uk/news/business-49884827

[36] Material Focus https://www.recycleyourelectricals.org.uk/

Globally, a record 53.6 million metric tonnes of electronic waste was produced in 2019 and it is projected that this figure will rise to 74 million metric tonnes by 2030. Currently, less than 18% of this electronic waste is recycled[37].

This electronic waste causes huge environment and climate damage.

- Toxic materials such as lead, zinc, nickel and chromium, get into the soil and water supply, causing permanent damage to people, animals and plants.
- Smoke produced by burning electronic waste leads directly to lung and heart diseases.
- For every 1 metric tonne of dumped electronic waste, 1.44 tonnes of CO_2 emissions are produced.

Greenpeace recently published a clearly written and comfortably structured report that examines the entire electronic product lifecycle. It highlights problem areas and companies that are successful in addressing issues in these areas[38].

Citizens should be encouraged to recycle surplus electronic devices. This will generate income. However, one of the reasons this kind of action is slow to gain traction may be related to data privacy. It is often a very complex task to ensure that all private data is wiped from an old device. For this reason, the **producers of digital devices should be required to simplify the end-of-life data wiping process**.

[37] Global Waste https://globalewaste.org/

[38] Guide to Greener Electronics (2017). Greenpeace. www.greenpeace.org/usa/reports/greener-electronics-2017

8 MEDIA

In the context of Cloud computing, the Green Cloud can be thought of as a super set of Green ICT. This is because Cloud computing is a service model for compute, not only a technology. For this reason, data types and usage fall into scope, as does the manner in which they are created and consumed.

8.1 Media Consumption

User behaviour: high-power machines are required for some activities, e.g. gaming but not others e.g. word processing. Machines that are not always used for gaming are wasteful of energy when deployed on less intensive tasks. The energy required to drive them is wasted when a lower power machine would do for the majority of work. **Maybe adaptive power consumption machines might be possible**.

8.2 Media Creation

In terms of data volume, the vast majority of data stored in the Cloud and accessed over the internet are not files for business use, they are media files for entertainment purposes. A report produced for the British Film Institute by ARUP[39] entitled The Screen New Deal describes the carbon footprint of the average Hollywood blockbuster as being equivalent to eleven trips to the moon. Clearly, this leaves a vast footprint on the environment; however, plans are being put in place to address this situation.

8.3 Media Streaming

The Global demand for computing power from internet-connected devices to deliver a range of streaming services such as: high resolution video streaming, email attachments, surveillance camera feeds and a new generation of smart TVs is increasing 20% a year. It consumed roughly 3-5% of the world's electricity in 2015 and could consume 20% by 2025, emitting up to 5.5% of the world's carbon emissions[40]. This is just for media streaming.

Other studies clearly show that although streaming media can be problematic in relation to the energy demands of all aspects of Cloud computing when compared to simply downloading and playing media files, the additional costs on the network in respect of capacity and energy consumption are marginal.

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39 https://www.arup.com/perspectives/publications/research/section/a-screen-new-deal-a-route-map-to-sustainable-film-production

40 Vidal, John (2017) 'Tsunami of data' could consume one fifth of global electricity by 2025. Climate Home News. https://www.climatechangenews.com/2017/12/11/tsunami-data-consume-one-fifth-global-electricity-2025/

However, in the case of interactive media, especially games, the additional costs can be considerable[41][42][43]. Playing Cloud-hosted online games not good for the environment or the climate.

Encourage citizens, through education, to use streaming services only when necessary, or regulate against unnecessary media streaming. Regulate against Cloud-based streaming of on-line games.

[41] Marsden, Matthew; Hazas, Mike; Broadbent, Matthew (2020) From One Edge to the Other: Exploring Gaming's Rising Presence on the Network. ICT4S2020: Proceedings of the 7th International Conference on ICT for Sustainability June 2020 Pages 247–254 https://doi.org/10.1145/3401335.3401366

[42] Mills, Evan, et al. (2017) An Energy-focused Profile of the Video Gaming Marketplace. Lawrence Berkeley National Laboratory

[43] Mills, Evan et al (2019). A Plug-loads Game Changer: Gaming System Energy Efficiency without Performance Compromise. California Energy Commission

9 PHYSICS

9.1 Data has Mass

Einstein's theory of special relativity is condensed into one of the most famous equations in science: E=mc2. It describes that energy and mass are equivalent. ICT operations involving digital data processing and storage consume energy; on the global scale this is a vast amount of energy. So, if all of this energy must result from an equivalent mass and if a bit of information is energy, then it also must have mass as well. This mass-energy-information equivalence principle is described by Vopson who extends Landauer's principle (linking logical and physical irreversibility), to further link thermodynamics and digital information theory through logical irreversibility[44]. Experiments have proven the process of deleting a bit of information dissipates heat energy, but after information is created, it can be stored with no energy loss.

This theory suggests that once information is created, it acquires finite mass. Unfortunately, taking the extremely small measurement needed at such precision may currently be unachievable. The next step in proving this could be through developing a sensitive interferometer similar to Virgo[45] or an ultra-sensitive Kibble balance[46]. However, if true, then the data deluge that we are currently experiencing and which exists largely in Cloud environments is changing the mass of the Earth and this could have significant astronomical consequences.

9.2 Information is Replacing Atoms

Primary industries exploit the Earth for minerals to manufacture materials and for fuels to power the manufacturing and manufactured machinery. Currently, 10^{21} bits of digital information are produced each year. Conservatively assuming a 20% annual growth rate for data stored at current data densities, it is estimated that after approximately 150 years, the number of bits produced will exceed the number of atoms that compose the Earth, approximately 10^{50} atoms. Before that, in approximately 130 years from now, the power required to sustain this digital production will exceed 18.5×10^{15} Watts, which is approximately equivalent to the total current planetary power consumption. Following this trajectory, it can be calculated (using the principle of mass-energy-information equivalence) that by 2245, bits of digital information will account for more than half of the Earth's mass[47].

What does this mean? If half of the Earth's current mass will be digital information in approximately 500 years, how much of it will be compensated for by the diminishment of atomic mass mentioned in the previous section? It is unlikely that the two will compensate for each other as much of the atomic mass is being converted into energy to power machinery. How much? What will the consequences be in relation to the damage already being done to the climate and the environment through converting natural resources into energy?

[44] Vopson MM. (2019) The mass-energy-information equivalence principle, Featured in AIP Advances issue 9. https://doi.org/10.1063/1.5123794

[45] https://www.virgo-gw.eu/#home

[46] https://www.npl.co.uk/kibble-balance

[47] Vopson MM. (2020) The information catastrophe, in AIP Advances 10, 085014; doi: 10.1063/5.0019941

This situation only adds to the existing global burdens of: climate change, environmental damage, population growth, food and water shortages, health care, energy security, and physical security. Add Cloud-borne data mass to the existential problems we face?

Long-term consequences of the data deluge are the acceleration of factors associated with environmental harm way beyond the more common sources of harm. Given the poor record the world has in containing its appetites, happily trading short-term pleasure for a long-term pain, this is unlikely to be a problem that can be easily solved. **Research into more efficient data storage devices and compute processors seems the only obvious solution**

10 MATERIALS

10.1 Construction

In the context of the Green Deal, sustainability and closed-loop manufacturing are becoming an increasingly important topic. Many closed-loop, organic alternatives to traditional manufacturing materials have been explored for over a decade and are now reaching commercial applications. One such material is chitin. Chitin is a long-chain polymer of a glucose derivative, which is a primary component of cell walls in fungi, the exoskeletons of arthropods, the radulae of molluscs, cephalopod beaks, and the scales of fish and lissamphibians[48]. The structure of chitin is comparable to cellulose, forming crystalline nanofibrils or whiskers. In terms of function, it may be compared to the protein keratin. Chitin has proved useful for several medicinal, industrial and biotechnological purposes, particularly where plastic and plastic-like materials are employed now.

Chitosan is a commercially produced derivative of chitin, which is soluble in water, whereas chitin is not[49]. Biolith is an experimental mixture of chemically transformed chitin solution and regolith (a loose mix of deposits that covers solid rock) to create a resilient, multi-use building material. In 2014, chitosan was shown to be a viable replacement for biodegradable plastic and is of direct application where all types of biodegradable materials are required[50]. Chitin nanofibers are extracted from crustacean waste and mushrooms for possible development of products in tissue engineering, medicine, and industry where resilience is required[51]. Biolith structures have been shown to offer sound alternatives to conventional construction materials like concrete and could become the predominant building material of the future.

Between them, chitin and chitosan may be able to replace many of the constructional and/or structural parts of ICT devices. Biolith may be able to replace concrete used in the data centre construction.

10.2 Electronic

The latest generation of processors and storage devices use chips at the 5nm scale. The expectation is that this scale is the limit for the current generation of material and techniques. To reach the 3nm scale and beyond, new techniques and materials will likely be required. This means increased energy will be consumed in processing to achieve more accurate laser etching and more exotic (and polluting) conductive, capacitive and substrate materials will be required. However, these materials and techniques are not expected to deliver massive increases in performance. This reality will result in significantly higher unit costs, for performance increases that are much less significant than was previously the case[52]. In other words,

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[48] Tang, WJ; Fernandez, JG; Sohn, JJ; Amemiya, CT (2015). "Chitin is endogenously produced in vertebrates". Curr Biol. 25 (7): 897–900. doi:10.1016/j.cub.2015.01.058. PMC 4382437. PMID 25772447

[49] Bedian, L; Villalba-Rodríguez, AM; Hernández-Vargas, G; Parra-Saldivar, R; Iqbal, HM (May 2017). "Bio-based materials with novel characteristics for tissue engineering applications - A review". International Journal of Biological Macromolecules. 98: 837–846. doi:10.1016/j.ijbiomac.2017.02.048. PMID 28223133

[50] Wyss Institute (2014) Promising solution to plastic pollution. The Harvard Gazette.

https://news.harvard.edu/gazette/story/2014/05/promising-solution-to-plastic-pollution/

[51] Ifuku, Shinsuke (2014). "Chitin and Chitosan Nanofibers: Preparation and Chemical Modifications". Molecules. 19 (11): 18367–80. doi:10.3390/molecules191118367. PMC 6271128. PMID 25393598

[52] LaPedus M, Sperling E (2020) Making Chips At 3nm And Beyond. Semiconductor Engineering

more environmental impact for fewer gains for fewer people at greater cost. Maybe the time has come to revisit chip design and manufacturing again. And to **encourage citizens not to buy high power machines** just because they are the latest thing; most people already do not need the kinds of performance on offer at the high end of computer performance.

https://semiengineering.com/making-chips-at-3nm-and-beyond/

11 POLICY ISSUES

11.1 Data Spaces

The European strategy for data aims at creating a single market for data that will ensure Europe's global competitiveness and data sovereignty. Common European data spaces will ensure that more data becomes available for use in the economy and society, while keeping companies and individuals who generate the data in control. One aim is to improve the sustainability and energy efficiency of Cloud computing.

The European Commission supports the creation of common European data spaces for various market sectors, to ensure enhanced access to privately held data, via existing data platforms. The EU data spaces will offer a secure and trusted environment for companies to share their data based upon voluntary agreements. In such a context, it is believed that these sectors will be able to benefit from shared infrastructures, systems and processes for the development and continuous improvement of their systems with high-quality insights.

The European Commission has begun an initiative to establish the rules for a number pf common European data spaces, which will support the single market for data, where data from public bodies, business and citizens can be used safely and fairly for the common good. An inception impact assessment has recently been published[53] which reveals that the main purpose currently is enable the sharing of data held by public authorities with the private sector. There is very little to demonstrate the possibility of businesses to collaborate at the moment. The discussion is abstract and no consideration is given to issues associated with implementation.

These data spaces seem to offer a form of logical federation enabling separate public and private Clouds to share data. It is explained neither how these spaces can be secured nor how they become sustainable nor achieve any increased level of energy efficiency. In fact, so far as energy efficiency is concerned, joining many small clouds together is not as energy efficient as creating a single Cloud large enough for the collaborators to participate within; such a Cloud would be easier to secure as well. There is also the issue of addressing and discoverability; how will traffic be routed to the data spaces: will the EU also set up a discreet domain naming service (DNS), or will it rely on existing DNS infrastructure? Running two separate DNS will increase energy consumption. **Comprehensive technical detail about how the EU Data Spaces will work in practice is needed.**

11.2 Competition

Recent reports that the EU is seeking new powers to break top tech giants[54] to increase business competition may not result in environmental benefits. A larger number of smaller competitors potentially translates into greater capacity overall (and therefore greater environmental impact) as many more smaller entities compete with each other to provide the same volume of service. **Legislators should consider their actions also in the context of the Green Deal when dealing with such competition issues in the digital realm**.

11.3 Unintended Consequences

When multiple policies are implemented there can, sometimes, be unintended consequences arising out of their conjunctions. For example, Ireland and Denmark have economic policies in place that are seen as positive by the hyperscalers which regard them as good host countries. However, the efforts made in these two countries, through their environmental policies, to move towards carbon neutrality have been neutralised because of the increased energy demand placed upon them through the

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53 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12491-Legislative-framework-for-the-governance-of-common-European-data-spaces

54 https://www.ft.com/content/c8c5d5dc-cb99-4b1f-a8dd-5957b57a7783

presence of the hyperscalers they have attracted[55]. **Policy-making, regarding digital services, should be carried out holistically, or at least giving due consideration to Green Deal impacts**.

[55] Kamiya G, Kvarnström O. (2019) Data centres and energy – from global headlines to local headaches? International Energy Agency https://www.iea.org/commentaries/data-centres-and-energy-from-global-headlines-to-local-headaches

12 ANNEX A: LIST OF POTENTIALLY SUITABLE KPIS FROM WHICH TO DERIVE STANDARDS

12.1 Generally Applicable Standards

ASHRAE 90.4-2016	Standards relating to heating, refrigerating and air-conditioning of facilities in general

12.2 Relevant KPIs from ISO/IEC related to DC and energy efficiency KPIs

ISO/IEC TR 20913:2016(en)	Data centres - Guidelines on holistic investigation methodology for data centre key performance indicators
ISO/IEC 21836:2020 ETSI 303470	Data centres — Server energy effectiveness metric (Variable)
no metrics defined	Data centres — Server energy effectiveness metric (Extended idle)
ISO/IEC 30134-1:2016/AMD 1:2018	General requirements
ISO/IEC 30134-2: 2016/AMD 1:2018	Power usage effectiveness (PUE)
ISO/IEC 30134-3: 2018/ AMD 1:2016 ISO/IEC TR 21897	Renewable energy factor (REF)
ISO/IEC 30134-4: 2017	Energy Efficiency for servers (Peak) (ITEEsv)
ISO/IEC 30134-5:2019 ITU L.1310	System utilisation
ISO/IEC 30134-6 (under development)	Energy reuse factor (ERF)
ISO/IEC 30134-8 (under development)	Carbon Usage Effectiveness (CUE)
ISO/IEC 30134-9 (under development)	Water Usage Effectiveness (WUE)
ISO/IEC TR 21897(under development)	Impact of ISO 52000 standards for energy performance of buildings

ISO/IEC TR 23050 (under development)	Data centres – excess electrical energy (XEEF)
ISO/IEC 30134-4:2017	Energy Efficiency for servers (ITEEsv)
ISO/IEC 30134-5:2017	Utilization for servers (ITEUsv)
ISO/IEC FDIS 21836 (under development)	Server energy effectiveness metric

12.3 Relevant KPIs and Guidelines from ITU-T related to DC and energy efficiency

12.3.1 Families

ITU-T L.13XX	Best practices for green data centres
ITU-T L.14XX	Principles of methodologies for assessing the environmental impact of ICT

12.3.2 ITU-T L series 13xx

1300	Best practices for green data centres
1301	Minimum data set and communication interface requirements for data centre energy management
1302	Assessment of energy efficiency on infrastructure in data centres and telecom centres L.1310 Energy efficiency metrics and measurement methods for telecommunication equipment L.1315 Standardization terms and trends in energy efficiency
1320	Energy efficiency metrics and measurement for power and cooling equipment for telecommunications and data centres
1321	Reference operational model and interface for improving energy efficiency of ICT network hosts
1325	Green ICT solutions for telecom network facilities
1330	Energy efficiency measurement and metrics for telecommunication networks
1331	Assessment of mobile network energy efficiency
1332	1332 Total network infrastructure Energy efficiency metrics
1340	Informative values on the energy efficiency of telecommunication equipment

1350	Energy efficiency metrics of a base station site
1360	Energy control for the software-defined networking architecture

12.3.3 ITU-T L series 14xx

1400	Overview and general principles of methodologies for assessing the environmental impact of information and communication technologies
1410	Methodology for environmental life cycle assessments of information and communication technology goods, networks and services
1420	Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organizations
1430	Methodology for assessment of the environmental impact of information and communication technology greenhouse gas and energy projects
1440	Methodology for environmental impact assessment of information and communication technologies at city level

12.4 The European Data Centre KPIs related to energy efficiency

EN 50600-4-1	KPIs – Overview and general requirements (ISO/IEC 30134-1)
EN 50600-4-2	KPIs – Power Usage Effectiveness (PUE – ISO/IEC 30134-2)
EN 50600-4-3	KPIs – Renewable Energy Factor (REF – ISO/IEC 30134-3)
EN 50600-4-4	KPIs – IT Equipment Energy Efficiency for Servers (ITEEsv – ISO/IEC 30134-4)
EN 50600-4-5	KPIs – IT Equipment Energy Utilisation for Servers (ITEUsv – ISO/IEC 30134-5)
CLC/TR 50600-99-1	Energy management – Recommended Practices
CLC/TR 50600-99-2	Environmental sustainability – Recommended Practices

12.5 Relevant EU Directives and Regulations

Directive EU 2015/863 (RoHS 3)	Deals with the restriction of hazardous substances. It restricts the use of particular hazardous substances in electrical and electronic equipment.

Regulation 1907/2006 (REACH)	Requires the registration, evaluation, authorisation, and restriction of chemicals to determine the level of protection required to assure human health and the environment during the production and use of chemical substances.
Directive 2012/19/EU	Applies to Waste Electrical and Electronic Equipment covering a variety of electronic equipment, encouraging the collection, treatment, recycling, and recovery of waste.