ITUPublications
Recommendations

International Telecommunication Union
Standardization Sector

Supplement

ITU-T L Suppl. 55 (10/2022)

SERIES L: Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant

---

Environmental efficiency and impacts on United Nations Sustainable Development Goals of data centres and cloud computing

ITU-T L-SERIES RECOMMENDATIONS

ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

OPTICAL FIBRE CABLES	
Cable structure and characteristics	L.100–L.124
Cable evaluation	L.125–L.149
Guidance and installation technique	L.150–L.199
OPTICAL INFRASTRUCTURES	
Infrastructure including node elements (except cables)	L.200–L.249
General aspects and network design	L.250–L.299
MAINTENANCE AND OPERATION	
Optical fibre cable maintenance	L.300–L.329
Infrastructure maintenance	L.330–L.349
Operation support and infrastructure management	L.350–L.379
Disaster management	L.380–L.399
PASSIVE OPTICAL DEVICES	L.400–L.429
MARINIZED TERRESTRIAL CABLES	L.430–L.449
E-WASTE AND CIRCULAR ECONOMY	L.1000–L.1199
POWER FEEDING AND ENERGY STORAGE	L.1200–L.1299
ENERGY EFFICIENCY, SMART ENERGY AND GREEN DATA CENTRES	L.1300–L.1399
ASSESSMENT METHODOLOGIES OF ICTS AND CO2 TRAJECTORIES	L.1400–L.1499
ADAPTATION TO CLIMATE CHANGE	L.1500–L.1599
CIRCULAR AND SUSTAINABLE CITIES AND COMMUNITIES	L.1600–L.1699
LOW COST SUSTAINABLE INFRASTRUCTURE	L.1700–L.1799

For further details, please refer to the list of ITU-T Recommendations.

Supplement 55 to ITU-T L-series Recommendations

Environmental efficiency and impacts on United Nations Sustainable Development Goals of data centres and cloud computing

Summary

Supplement 55 to ITU-T L-series Recommendations explores the environmental sustainability of data centres during their entire life cycle, factoring in a broad spectrum of energy and environmental aspects that needs to be addressed to achieve the relevant United Nations Sustainable Development Goals, to support the development of sustainable data centres and cloud-computing services. An integrated approach addressing both technical and implementation challenges is applied to yield actionable insights to policy makers and industry experts.

As the role of data centres and cloud computing increases, so are the concerns over their energy use and its cost, as well as the associated impacts on climate change and environment. In recent years, the data centre and cloud industry has made great progress in enhancing energy efficiency and adopting renewable energy sources. However, a sole focus on energy efficiency may cause burden shifting and overlook other relevant environmental impacts stemming from other parts of the data centre life cycle and cloud-computing value chain.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T L Suppl. 55	2022-10-27	5	11.1002/1000/15216

Keywords

Cloud computing, data centre, impact assessment, life cycle, policy gap analysis, sustainable development goals, sustainability matrix.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents/software copyrights, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the appropriate ITU-T databases available via the ITU-T website at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Introduction

Data centres (DCs) can be described as computer warehouses that store a large amount of data for different organizations in order to meet their daily transaction processing needs [b-JRC, 2021]. DCs contain servers for the collection of data and network infrastructure for their utilization and storage. DCs are the backbone of global information technology infrastructures and help to sustain the constant need for data management.

The energy intensity of the DC industry is well known, with an estimated global electricity demand of 200 TWh, or ~0.8% of global final electricity demand [b-Masanet, 2020].

On top of being an energy intensive industry, there are other environmental impacts that cannot be overlooked, such as water consumption. DCs consume water directly for cooling (in some cases more than half is sourced from potable water), and indirectly through the water requirements of non-renewable electricity generation [b-Mytton].

Other environmental life cycle impacts of DCs are also significant. Across the building stage, operation, expansion or demolition, there are numerous environmental impacts that need to be considered when assessing the impact of DCs – impacts that can be linked to the UN Sustainable Development Goals (SDGs) [b-UN].

The SDGs, launched in 2015 by the United Nations under the 2030 agenda for sustainable development, provide a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 SDGs, which are an urgent call for action for all countries – developed and developing – in a global partnership. The UN recognizes that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all the while tackling climate change and working to preserve the oceans and forests.

This Supplement gives an overview of the sustainability impacts of DCs, their correlation with the SDGs and how these can interact. Moreover, it refers to applicable indicators and standards, and describes relations between the SDGs and DC sustainability impacts. Finally, some framing policies that incentivize the development of sustainable DCs and the cloud are identified and described in Appendix I.

Supplement 55 to ITU-T L-series Recommendations

Environmental efficiency and impacts on United Nations Sustainable Development Goals of data centre and cloud computing

1 Scope

This Supplement adopts a multi-impact and life cycle perspective and addresses the following aspects of data centres (DCs) and cloud computing:

- an overview of environmental and energy impacts of DCs and cloud computing taking a life cycle approach;
- an overview of socio-economic impacts;
- a mapping of related sustainability and energy indicators and standards;
- an overview of links to the 17 Sustainable Development Goals (SDGs).

2 References

None.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 cloud computing [b-ITU-T Y.3500]: Paradigm for enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on-demand.

NOTE 1 – Examples of resources include servers, operating systems, networks, software, applications, and storage equipment.

NOTE 2 – This Supplement uses terminology defined in [b-UNEP terms] for life cycle and [b-ITU terms].

3.1.2 data centre [b-ITU-T X.1053]: A facility used to house computer systems and associated components, such as telecommunication and storage systems.

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

CUE	Carbon Usage Effectiveness
DC	Data Centre
DCiE	Data Centre Infrastructure Efficiency
EDE	Electronics Disposal Efficiency
GHG	Greenhouse Gas
ICT	Information and Communication Technology
IoT	Internet of Things
IT	Information Technology

KPI	Key Performance Indicator
PPA	Power Purchase Agreement
PUE	Power Usage Effectiveness
pPUE	Partial Power Usage Effectiveness
SDG	Sustainable Development Goal
UPS	Uninterruptible Power Supply
WEEE	Waste Electrical and Electronic Equipment
WUE	Water Usage Effectiveness

5 Conventions

None.

6 Data centre environmental and energy impacts

This clause gives an overview of the environmental impacts inherent to DCs during their life cycle, which are directly and indirectly related to the SDGs and outline some of the mitigation measures that can be used in order to minimize such impacts.

From the environmental perspective, not only information and communication technology (ICT) goods but also all aspects of the life cycle of the infrastructure counts – from the site prospection to the development and construction of the shell of the actual building, retrofitting or expansion of older structures, the actual operation of the DC and the end of life and demolition.

6.1 Electricity consumption and production

Electricity usage during operation is the main source of environmental impact of a DC due to the high intensity of activities such as processing, storing and transmitting of data to the Internet.

Since 2010, the number of Internet users worldwide has doubled, while global Internet traffic has grown 12-fold, at ~30%/year.

Demand for data and digital services is expected to continue its exponential growth over the coming years with a 2020 estimate expecting global Internet traffic to double by 2022 to 4.2 ZB/year (4.2 trillion GB/year). The number of mobile Internet users is projected to increase from 3.8 billion in 2019 to 5 billion by 2025, while the number of Internet of things (IoT) connections is expected to double from 12 billion to 25 billion. These trends are the driving force in the exponential growth of the demand for DCs and network services [b-IEA].

With most of the world's Internet protocol traffic going through DCs, greater connectivity is therefore propelling demand for DC services and energy use (mostly electricity), with multiplying effects: for every bit of data that travels through the network from DCs to end users, another five bits of data are transmitted within and among DCs.

[b-IEA] estimates the global DC electricity demand in 2019 at ~200 TWh or about 0.8% of global final electricity demand. Also, in the EU, in 2015, the amount of electricity consumed was estimated to correspond to ~2.25% of the total EU-28 electricity [b-Bertoldi, 2018]. Nevertheless, the strong demand for electricity by DC services is held back by the energy efficiency improvements of servers, storage infrastructure and the DC infrastructure.

Other developments include a continued trend towards larger, more efficient DCs, despite edge DCs demanding smaller DCs closer to final consumers. Moreover, emerging technologies like artificial intelligence, machine learning and blockchain will increase the request for DC and increase their energy need.

In the JRC report on DC developments related to the EU code of conduct, there is a clear indication that although computing demand is growing, the power usage effectiveness (PUE) values of participants have improved [b-Bertoldi, 2017]. For example, companies like Google are reporting delivery of around seven times as much computing power with the same amount of electrical power compared to 5 years ago [b-Google, 2020].

With the decline in renewable energy prices over several years and with electricity reaching up to 70% of DC costs [b-Ratka], some companies have started to look into purchasing or even producing their own electricity via renewables. The largest players in the ICT sector are also the largest buyers of renewables (Figure 1).

Figure 1 illustrates the largest US energy buyers in 2019.

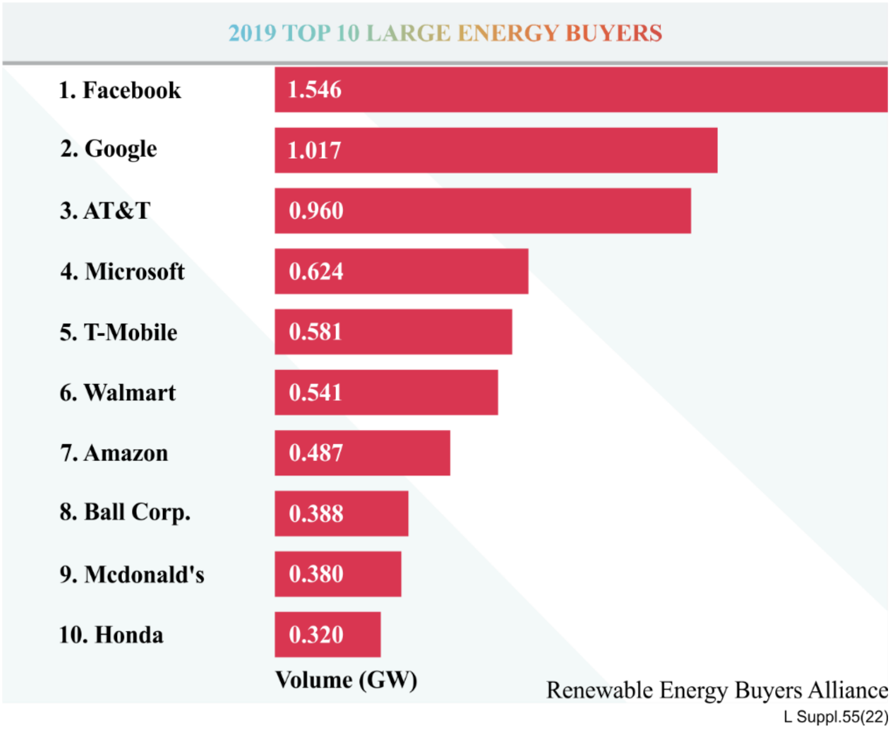

Figure 1 – Largest US energy buyers in 2019 (GW) [b-Ratka]

DCs can be considered a significant demand side player in a local energy grid, including their role in demand side management. Here DCs could play a positive role by providing opportunities for energy storage, thereby allowing grids to integrate larger shares of renewables. Some hyperscale DCs are using strategies like time shifting of computing tasks to periods of the day where the share of renewables is highest.

Another positive impact from the operation of DCs is the opportunity to use the waste heat from the server halls directly in neighbouring heating networks. Being a natural by-product of operation, this waste heat is used in district heating of the local communities in which the DC is installed thereby helping the decarbonization of cities.

An impact that is theoretically small, but one which is hard to avoid, is the greenhouse gas (GHG) emissions generated by the fossil fuels used by emergency generators. Having to provide a fully functioning data flow, DCs often need to rely on standby heavy-duty diesel generators to ensure that the electricity flow remains uninterrupted during grid outages until the normal functioning of the grid is re-established. For example, the EU has demanded an industrial emission directive license for back-up generators servicing data facilities with a total rated thermal input exceeding 50 MW i.e., if the back-up generator operates for more than 18 h/year. The medium combustion plant directive also regulates pollutant emissions from the combustion of fuels in plants with a rated thermal input equal to or greater than 1 MWth (thermal) and less than 50 MWth.

6.2 Data centre water consumption

DC energy consumption may be the most significant environmental aspect in the life cycle of a DC. However, there is another very important aspect that needs to be taken into consideration when evaluating the sustainability impact of this type of infrastructure, which is water consumption. Water is an essential element for life on the planet and crucial for numerous sectors, and the availability and quality of water is a growing global concern. According to [b-Mytton], future projections suggest that water demand will increase by 55% between 2000 and 2050 due to growth from manufacturing (+400%), thermal power generation (+140%) and domestic use (+130%). ICT is one of the sectors contributing to the demand for water.

There are two main activities within DCs that consume water: Water used in electricity generation and water used for cooling.

According to [b-Mytton] in 2014, a total of 626 Gl of water use was attributable to US DCs. Although some of the water being used in cooling the DCs emerge from non-potable sources, some DCs are still drawing more than half of their water from potable sources (Figure 2). This is especially important when large numbers of DCs are placed near densely populated areas in which the data is being consumed. It is not rare that DCs are located in areas where popular water consumption is already affected by droughts and high stress in aquifers.

Figure 2 illustrates the water source distribution per year for one global DC operator.

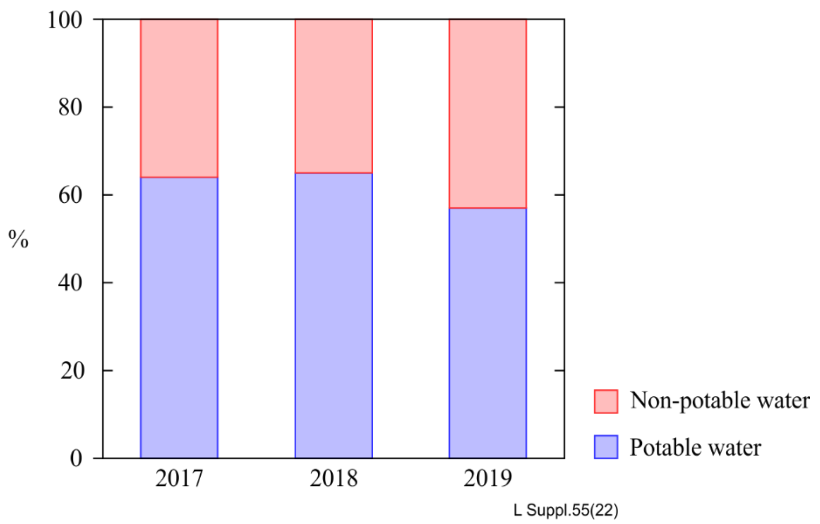

Figure 2 – Water source distribution per year for Digital Realty, a large global data centre operator [b-Mytton]

6.2.1 Water consumption in electricity generation

The electricity used to power DCs also requires significant volumes of water. Power plants burn fuel to heat water, generating steam to turn a turbine, which then generates electricity. Results are often seen from the huge cooling towers next to power plants [b-Mytton].

The volume of water used in electricity generation is four times greater than that used onsite for cooling: 7.6 l of water is used for every kilowatt hour of electricity generated, compared to 1.8 l/kWh of DC energy use.

Only solar and wind power do not use water in the generation – instead the manufacturing process contributes to the majority of their water footprint.

Figure 3 illustrates direct and indirect level of water consumption in DCs in the USA.

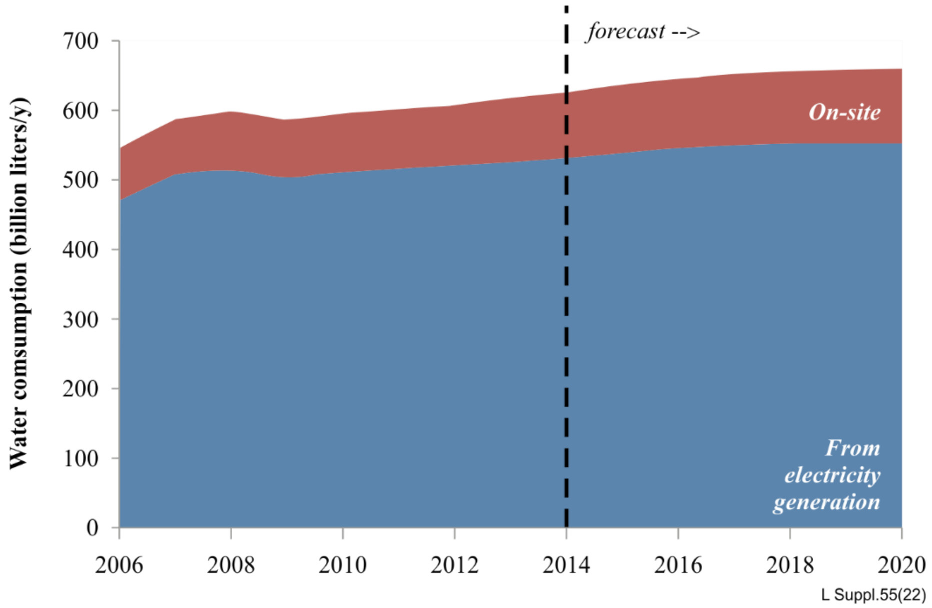

Figure 3 – Direct vs indirect US data centre water consumption [b-Mytton]

6.2.2 Water use in data centre cooling

Besides bytes, heat is another output from the ICT goods of a DC. To keep the DCs at an ideal operating temperature, water is often used to cool server rooms. However, there are several alternative heat removal methods to cool information technology (IT) equipment and transfer the heat outside. The idea is to use a heat exchanger to transfer thermal energy from one fluid to another. Chilled water systems usually cost less than others using, fpr example, glycol or air-cooled chillers. The efficiency improves with DC capacity, and the cooling system is considered very reliable and can be optimized to operate at higher water temperatures. Some DCs use cooling towers where the external air travels across a wet medium so that the water evaporates. Other DCs use adiabatic economizers where water is sprayed directly into the air flow or on to a heat exchange surface, thereby cooling the air entering the DC. In both the techniques, the evaporation results in water loss. A small 1 MW DC using one of the above types of traditional cooling can use ~25.5 Ml of water per year [b-Schneider Electric].

6.3 Data centre waste

6.3.1 E-waste

The global e-waste monitor [b-UNU/UNITAR] estimated that 53.6 Mt of electronic waste was generated worldwide in 2019, up 21% in just 5 years. According to the report, Asia generated the greatest volume (some 24.9 Mt), followed by the Americas (13.1 Mt) and Europe (12.0 Mt), while Africa and Oceania generated 2.9 Mt and 0.7 Mt, respectively [b-ITU IW].

With the constant growth of new and refurbished DCs comes an increase in waste electrical and electronic equipment (WEEE), or e-waste. However, due to long primary life cycles of the critical DC infrastructure, such as generators and uninterruptible power supply (UPS), these are not a major contributor to e-waste. On the other hand, all ICT goods or parts that are optimized for efficiency and refreshments may be significant contributors of e-waste. These include servers and other hardware parts.

DC equipment consists almost entirely of largely (> 99%) composed "common" metals (e.g., steel, copper, aluminium) and polymers (e.g., acrylonitrile butadiene styrene, poly(vinyl chloride), poly(butylene terephthalate)), while 10 critical raw materials typically make up 0.2% of components. Publicly available information about such materials in DC equipment is limited and focused on enterprise server compositions.

The supply risk to critical raw materials is high; despite this, their recycling rate from WEEE is estimated to be only ~1%. Some metals are recycled more often because of their stable properties, consistent qualities, and well-established and more economically viable recycling technologies, including having a market for resale. However, end-of-life management companies face many challenges in recovering critical raw materials and rare earth elements from infrastructure equipment, particularly the viability of technology and economic recovery, and these are further compounded by the falling value of the WEEE, meaning there is less value to extract. In general, DC WEEE contains more high-grade recycling materials than small IT devices such as laptops. For example, DCs use high-grade circuit boards and backplanes that typically have a higher precious metal content than the typical circuit boards from an individual consumer device or other small ICT goods.

Figure 4 illustrates common electrical and electronic equipment components and materials found in DCs.

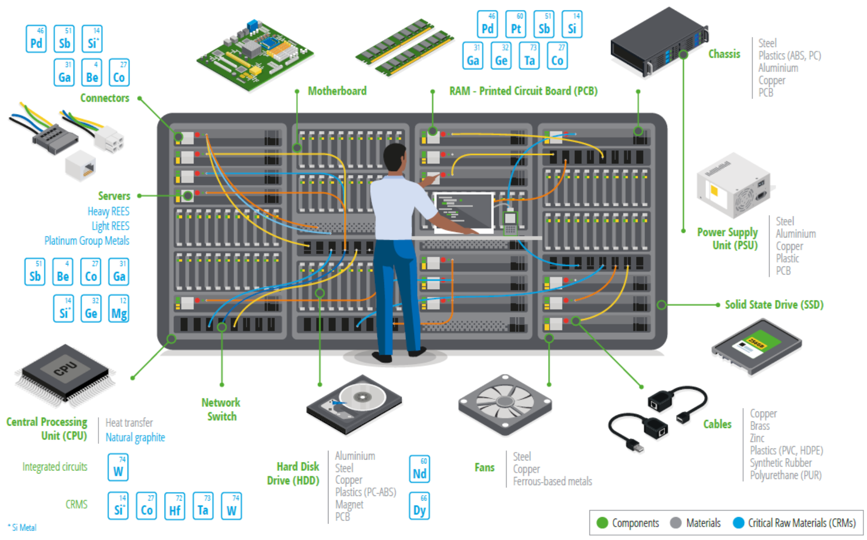

Figure 4 – Common electrical and electronic equipment components and materials found in data centres, including critical raw materials of high economic importance [b-JRC, 2015]

6.3.2 Waste heat

Not all impacts arising from the operation of DCs are negative. The energy intensity of DCs comes with a great amount of waste heat that has the potential to be used elsewhere, namely in the heating of the supporting structures of the DC, and most significantly, in district heating infrastructure.

Waste heat utilization may represent an important step for DC operators to reach a future net-zero energy goal. Some Nordic countries are already implementing this sustainability measure by channelling DC hall server waste heat into district energy systems for reuse. Stockholm's data parks for example, aim to use waste heat from DCs to heat 10% of the city by 2035. This trend is expected to become more omnipresent as EU-wide policies are drafted. For this to succeed, waste heat recovery should be inserted in the design stage of the cooling system of new or refurbished DCs. Not all DC cooling systems are sufficiently conducive or efficient to extract energy-minimizing thermal losses. Liquid cooling, for example, is more efficient than air cooling for waste heat recovery.

Figure 5 illustrates waste heat usage for district heating.

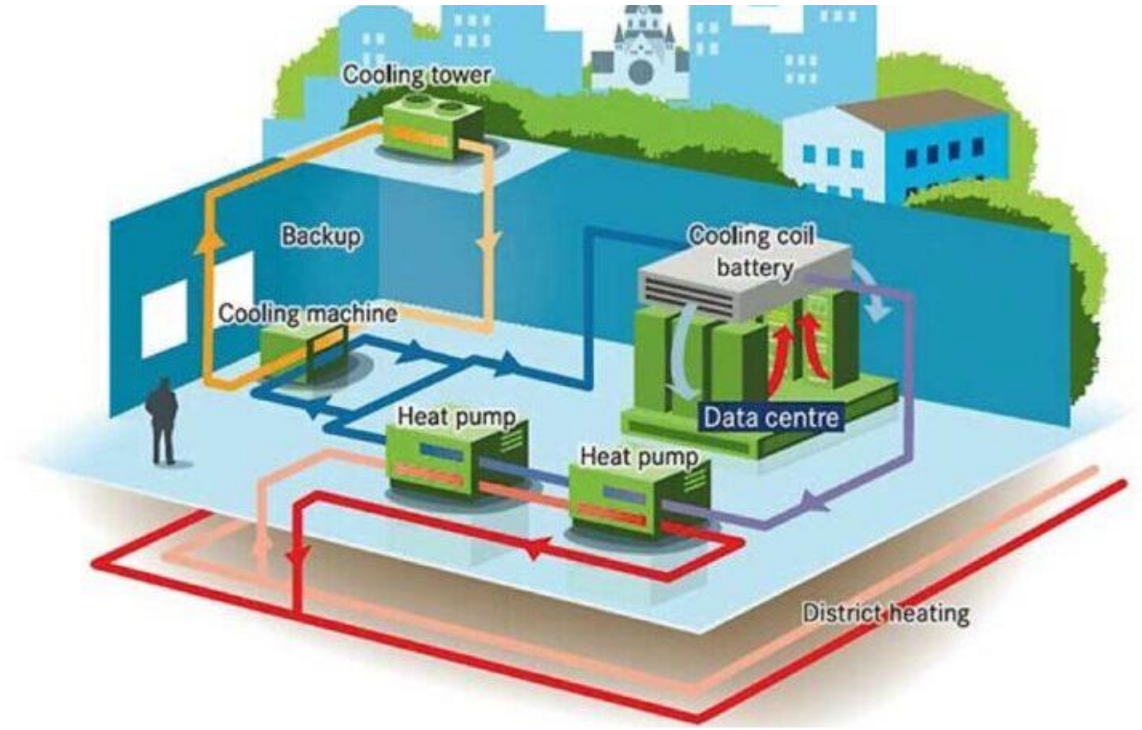

Figure 5 – Waste heat usage for district heating [b-Nortek]

6.4 Embedded carbon in DC construction materials

After addressing the operation of the DC, aspects such as circularity, the impact of other life cycle stages and, potentially, carbon offsets or carbon credits draws the attention of operators.

NOTE – Carbon offsets and credits cannot replace activities to reduce emissions. These lie outside the scope of this Supplement and are not further discussed.

As previously mentioned, one of the most commonly applied measures to minimize the environmental impact of DCs is through the production of renewables onsite and through the use of power purchase agreements (PPAs) from electricity suppliers.

However, procurement of renewables cannot address the embodied GHG emissions. The Green Building Council [b-WGBC, 2019] states that, "In a building life cycle, embodied carbon is … GHG emissions associated with the non-operational phase of the project." It further states, "This includes emissions caused by extraction, manufacture, transportation, assembly, maintenance, replacement, deconstruction, disposal and end of life aspects of the materials and systems that make up a building. The whole life cycle GHG emissions of a DC hence include both the embodied GHG emissions and the emissions associated with the operations of the DC.

GHG emissions in a building can be associated with the following life cycle stages.

- End of life: GHG emissions associated with deconstruction or demolition, transport from site, waste processing and disposal phases of a building or infrastructure's life cycle, which occur after its use.
- Operation: The emissions associated with the energy used to operate the building or in the operation of the infrastructure.
- Production: The emissions caused in the production of the materials and construction phases of the life cycle before the building or infrastructure enters use. In contrast to other categories of emissions listed here, these emissions have already been released into the atmosphere before the building is occupied or the infrastructure begins operation.

- Maintenance: Emissions associated with materials and processes needed to maintain the building or infrastructure during use such as for refurbishments. These are in addition to the operational carbon emitted due to heating, cooling, power, etc.

Traditionally, embodied emissions are overlooked, but as operational emissions are reduced, their relative importance will continue to grow, and DC operators must also start addressing them.

Embodied emissions can be affected by several factors. The choices of structure, materials used and their emissions intensity in the production and transport stages are all to be taken into consideration. On the other hand, there are several materials that can absorb or sequester emissions, which can offset emissions from other life cycle stages.

Opportunities for reducing or eliminating embodied emissions vary considerably and will differ between the types of projects as well as by region [b-WGBC, 2019]. In general, the greatest savings can be realized due to choices at the early stages of a project. As a project progresses, it becomes more challenging and more expensive to make design changes in order to reduce embodied emissions.

Figure 6 illustrates the emission reduction potential.

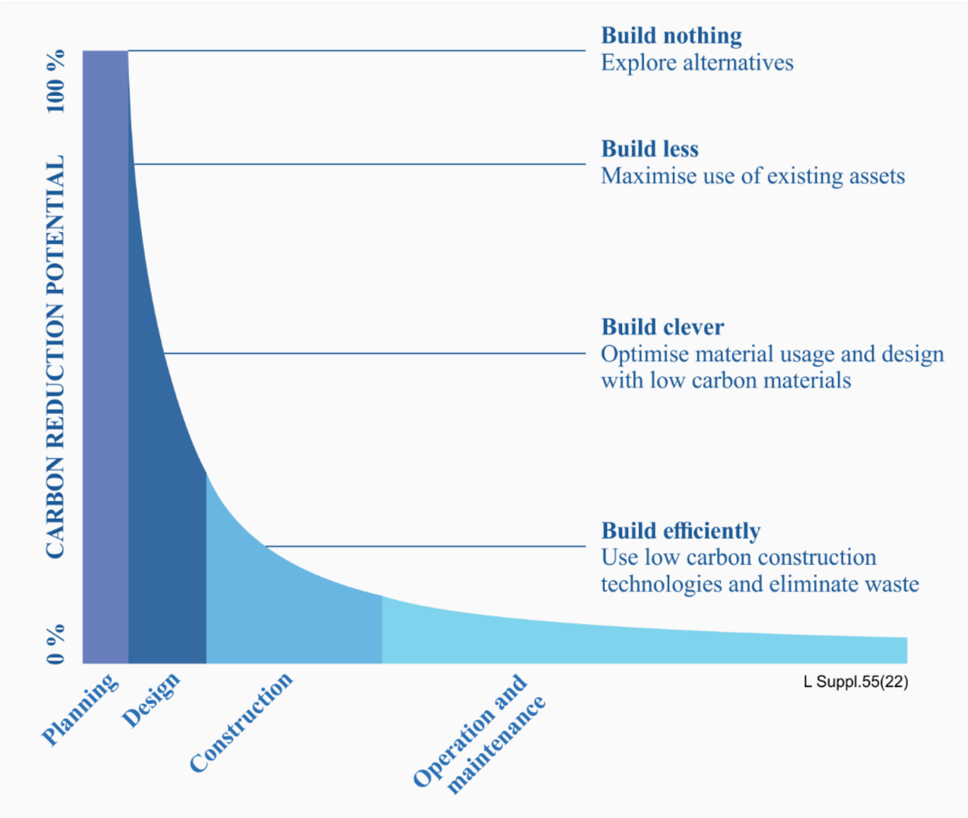

Figure 6 – GHG emission reduction potential [b-WGBC, 2019]

In principle, embodied emissions should be considered at a very early stage so that all interested parties are aware of the GHG emissions impact of a project. The use of traditional materials should be questioned when there are alternatives that may achieve the same solution with less impact.

For example, [b-Spaun] proposes the use of cement incurring low GHG emissions. In Austria, cement clinkers are produced in rotating kilns with a preheater. This state-of-the-art technology enables the use of waste heat for preheating fuels and raw materials, thus reducing the overall energy consumption for cement production. Moreover, several cement companies in Austria supply waste heat for district heating. In addition to energy efficiency, resource efficiency is an important pillar of cement production in Austria: for each tonne of cement produced, 441 kg of secondary materials are reused [b-Spaun].

Other manufacturing techniques are also being developed, for example, Sweden is developing a new manufacturing process in steel production, resulting in so called green steel.

Figure 7 illustrates embodied energy and embodied GHG emissions of different building materials.

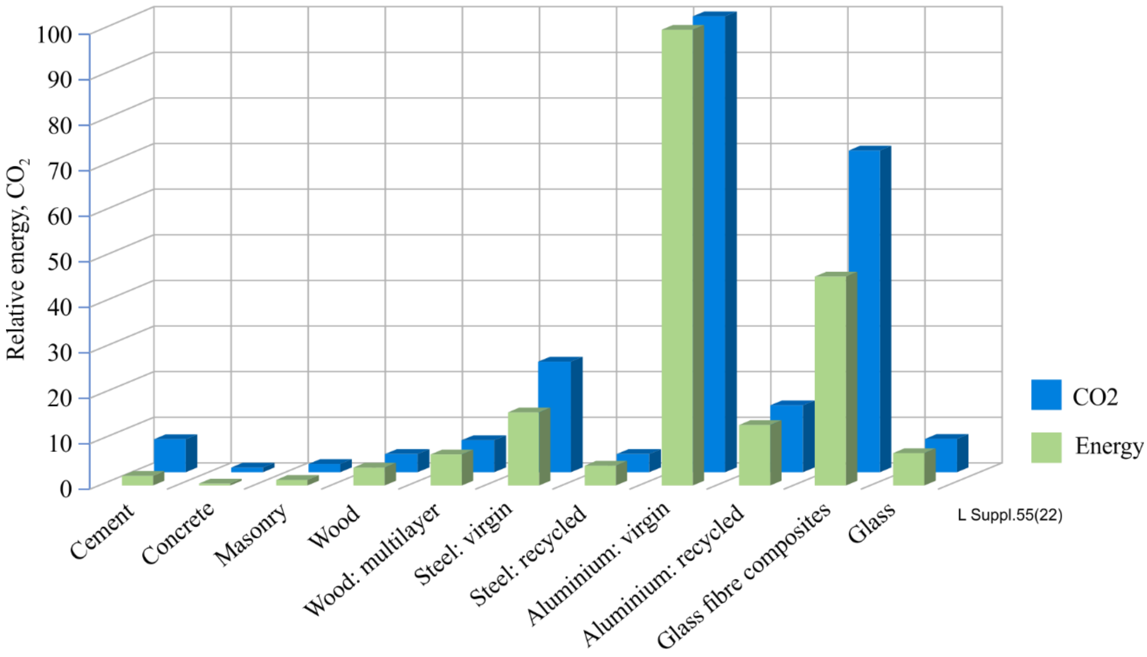

Figure 7 – Embodied energy [MJ/kg] and embodied emissions [kg CO_2/kg] of different building materials [b-WGBC]

7 Socio-economic impacts

DCs, especially large hyperscale DCs, have a great footprint where they are implemented, in terms of spatial, economic, environmental and social impact. The question is how much and to what extent DCs are integrated into the community.

Several studies have been performed on the socio-economic impacts of the implementation of DCs in local communities. A thesis examining the social and environmental impacts of the development and operation of DCs, using a Facebook DC in Prineville, Oregon as a case study has explored what impact the technology industry has on the local social and natural environment, as well as the broader implications of DC operations [b-Ipsen]. Firstly, [b-Ipsen] concludes that big data companies have tried to accommodate local concerns regarding the facilities and to integrate them within the social fabric of the communities in which they are built and operated. Consequently, in the short term, they appear to have little or no impact on the social life of local citizens. Secondly, the environmental impacts of DCs are difficult to determine at a global scale.

Based on the foregoing, DCs appear almost entirely beneficial to community life, especially to small rural towns. There are cases in the USA that show that the presence of DCs from Facebook or Apple have lifted the socio-economic conditions of rural communities in which they were installed. However, even if it may be evident that the presence of DCs can be beneficial for communities, new employments are usually short term, with the manpower used being mainly in the construction phase, via subcontracting local companies, while for the operation stage, traditionally, companies tend to hire highly qualified professionals from elsewhere.

This is challenged by [b-Oxford Economics] a study commissioned by Google, in which it is affirmed that their DCs provide important local spill-over effects to their host communities. Within a few years of a DC opening, most communities experienced employment gains (beyond those at the DC itself) or increases in the number of college-educated residents. According to this research each of these benefits was spurred by Google's decision to locate a DC in that community. Moreover, it is likely that these benefits persist and continue to grow beyond the first few years of the DC opening.

Using a regression framework, counties hosting a Google DC were found to have experienced more job growth than the matched controls. The impact began 1 to 2 years prior to the opening of a DC (presumably due to site acquisition, construction and related activities) and continued throughout the tested period (3 years beyond the opening date). Also, Google's commitment to long-term renewable energy seems to have spurred economic gains in addition to the environmental benefits that have resulted from the programme. Specifically, because of Google's clean energy commitment, $2.1 billion was invested in eight new renewable energy projects. The construction of these projects created more than 2 800 (temporary) construction jobs.

A CBRE's data centre solutions group produced a white paper that evaluated the overall cost of leasing a one MW data centre throughout the U.S. and the relation between the jobs and the capital investment [b-CBRE, 2021]. The paper declared that data centres tend to be relatively low on employment. Typical headquarters, manufacturing, or shared service operations can have between 200 and 1 000 jobs onsite. By comparison, the number of jobs at a typical DC can be anywhere between five and 30. Nevertheless, it was indicated that capital investment is another driver of tax revenue growth for the communities. While low on employment, DCs are highly capital intensive. Capital investment in a DC could be around $50 million on the low and up to $1 billion on the high end depending on the type of facility. This investment comes in the form of the construction of a new building, purchases of computer servers and ultimately consumption of electricity, to name a few. Some ways a state and community make money from DC capital investment may be through sales taxes on construction materials, sales or use taxes on equipment purchases, sales taxes or franchise fees on power consumption, personal income taxes from construction and permanent jobs, local income taxes from construction and permanent jobs or real estate taxes on a newly constructed or renovated building.

Another report on the economic impact of a hyperscale DC establishment in Norway [b-Menon], states that, in the public debate, it is often claimed that DCs contribute with a relatively small economic impact and that this economic impact only occurs in IT-related industries. However, this does not take into consideration the investment and construction phase, and more importantly, effects for the broader supply chain and the catalytic effects resulting from DC establishment. The report estimates the effects of a potential hyperscale DC that is expected to be built in three stages over a period of 10 years, where operations start gradually once the individual steps have been completed. They have estimated that a DC will contribute to national employment with more than 6 800 full-time workers over a 12-year analysis period, and more than 450 full-time workers in the following years when the DC is in full operation. In addition, an economic impact of more than NOK 5.2 billion could be linked to DC establishment over the period of the analysis, with approximately NOK 320 million in annual economic impact thereafter [b-Menon].

8 Energy and sustainability measurement indicators available for DCs and cloud computing

This clause identifies the different indicators available for environmental impact assessment of DCs and cloud computing.

Increased efficiency is important for DC developers and operators. Overall, it comes down to a matter of reducing operating costs. However, for these efficiency improvements to occur, measuring and monitoring applicable key performance indicators (KPIs) is required.

8.1 Green Grid indicators

The Green Grid consortium has introduced PUE, currently the prevailing metric, which was first published in 2016 in an international standard in [b-ISO/IEC 30134-2] (see clause 10.1) [b-Reddy]. The Green Grid consortium has also established the partial power usage effectiveness (pPUE), based on the PUE but referring to one zone in the DC, and the data centre infrastructure efficiency (DCiE), which measures the efficiency of DCs by relating the power consumption to the IT equipment. PUE, pPUE and DCiE help operators monitor the efficiency of DCs. The consortium has also introduced metrics such as carbon usage effectiveness (CUE), water usage effectiveness (WUE) and electronics disposal efficiency (EDE) to measure the carbon footprint, the water consumption per year, and the disposal efficiency of the DCs respectively [b-Reddy].

Of the indicators previously mentioned, PUE might be the most well known. Introduced by the Green Grid in 2007 and adopted by the industry as the indicator of choice, the PUE is intended to help operators understand DC efficiency (or rather its inverse) and reduce energy consumption. It is defined in [b-ITU-T L.1302] as the ratio of total DC input power to that used by IT equipment.

NOTE – In ITU-T L.1400 series Recommendations, equipment is usually referred as goods.

The higher the PUE value, the lower is the efficiency of the facility as more "overhead" energy is consumed for powering the IT goods. The ideal PUE value is one that indicates the maximum attainable efficiency with no overhead energy. This is not attainable at present due to the consumption of electricity by UPS, fans, pumps, transformers, lighting and other auxiliary equipment, in addition to the consuming IT load.

8.2 A wider set of indicators

A more extensive list of energy efficiency indicators has been collected by [b-Reddy] as presented in Table 1, which gives an overview of the metrics. Table 1 lists the unit of each metric, the objective, the optimal value, and the category to which it belongs.

Table 1 – Energy efficiency metrics overview [b-Reddy]

Acronym	Full name	Unit	Objective	Optimal	Category
APC	Adaptability power curve	Ratio	Maximize	1.0	Facility
CADE	Corporate average data centre efficiency	Percentage	Maximize	1.0	Facility
CPE	Compute power efficiency	Percentage	Maximize	1.0	Facility
DCA	Data centre adapt	Ratio	Minimize	$-\infty$	Facility
DCcE	Data centre compute efficiency	Percentage	Maximize	1.0	Server
DCeP	Data centre energy productivity	UW/kWh	Maximize	∞	Facility
DCiE	Data centre infrastructure efficiency	Percentage	Maximize	1.0	Facility
DCLD	Data centre lighting density	$kW/foot^2$	Minimize	0.0	Facility
DCPD	Data centre power density	kW/rack	Maximize	∞	Rack
DCPE	Data centre performance efficiency	UW/power	Maximize	∞	Facility
DC-FVER	Data centre-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 centre performance per energy	Ratio	Maximize	1.0	Facility
DWPE	Data centre workload power efficiency	Perf/W	Maximize	∞	Server
EES	Energy expenses	Ratio	Maximize	1.0	Facility
EWR	Energy wated ratio	Ratio	Minimize	0.0	Facility
GEC	Green energy coefficient	Percentage	Maximize	1.0	Facility

Table 1 – Energy efficiency metrics overview [b-Reddy]

Acronym	Full name	Unit	Objective	Optimal	Category
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
$PUE_{1–4}$	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/W	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

[b-Reddy] also identifies environmental KPIs beyond energy efficiency, including water usage effectiveness or carbon efficiency. Table 2 shows these additional indicators.

Table 2 – Green metrics [b-Reddy]

Acronym	Full name	Unit	Objective	Optimal	Category
–	CO_2 savings	Ratio	Maximize	1.0	Facility
CUE	Carbon usage effectiveness	$kgCO_2/kWh$	Minimize	0.0	Facility
EDE	Electronics disposal efficiency	Percentage	Maximize	1.0	Facility
ERE	Energy reuse effectiveness	Percentage	Minimize	0.0	Facility
ERF	Energy reuse factor	Percentage	Maximize	1.0	Facility
GEC	Green energy coefficient	Percentage	Maximize	1.0	Facility
GUF	Grid utilization factor	Percentage	Minimize	0.0	Facility
MRR	Material recycling ratio	Percentage	Maximize	1.0	Facility
Omega	Water usage energy/ω	Ratio	Minimize	0.0	Facility
TCE	Technology carbon efficiency	$poundsCO_2/kWh$	Minimize	0.0	Facility
TGI	The Green Index	Ratio	N/A	N/A	Facility
WUE	Water usage effectiveness	l/kWh	Minimize	0.0	Facility
NOTE – For further information on KPI calculation, see Appendix A of [b-Reddy].					

9 Standards

There are several international standards that DC operators can refer to, giving them the tools to construct and operate the DC in an efficient and environmental sound way.

9.1 DC specific environmental and sustainability standards

The parts of ISO/IEC 30134 include specific KPIs for DCs.

- [b-ISO/IEC 30134-1]: Overview and general requirements
- [b-ISO/IEC 30134-2]: PUE
- [b-ISO/IEC 30134-3]: Renewable energy factor
- [b-ISO/IEC 30134-4]: IT equipment energy efficiency for servers
- [b-ISO/IEC 30134-5]: IT equipment utilization for servers
- [b-ISO/IEC 30134-6]: Energy reuse factor
- [b-ISO/IEC 30134-7]: Cooling efficiency ratio
- [b-ISO/IEC 30134-8]: CUE
- [b-ISO/IEC FDIS 30134-9]: WUE

Building standards

A different type of sustainability standard for DCs relates to voluntary construction schemes that certify buildings like the UK Building Research Establishment's Environmental Assessment Method (BREEAM) scheme or its American counterpart from the US Green Building Council under the Leadership in Energy and Environmental Design (LEED) certification scheme.

The [b-BREEAM] sustainability assessment method is used for masterplan projects, infrastructure and buildings. It recognizes and reflects the value in higher performing assets across the built environment life cycle, from new construction to in-use and refurbishment.

In this edition, BREEAM have produced two new annex documents which must be used in conjunction with the BREEAM international new construction 2016 manual for all data centre assessments. Annex 1 includes background information and revised issues which resolves issues in the BREEAM NC 2016 manual. Annex 2 gives an overview of all changes to the technical criteria in BREEAM NC 2016.

LEED building design and construction: data centres

This rating system is specifically designed and equipped to meet the needs of high-density computing equipment such as server racks, used for data storage and processing. A typical building is designed to meet heating and cooling needs for occupant comfort, whereas a DC must provide massive cooling power for its servers. LEED *Building design and construction: Data centres* [b-USGBC] addresses the unique needs of DCs as energy-intense buildings to help improve efficiency.

Finally, the EU *Data centres code of conduct* [b-JRC, 2023], also a voluntary scheme, was established in response to increasing energy consumption in DCs and the need to reduce the related environmental, economic and energy supply security impacts. The aim of [b-JRC, 2023] is to inform and stimulate operators and owners to reduce energy consumption in a cost-effective manner without hampering DC mission critical function. [b-JRC, 2023] aims to achieve this by improving understanding of energy demand within the DC, by raising awareness and recommending energy efficient best practices and targets. [b-JRC, 2023] is a voluntary initiative aimed to bring interested stakeholders together including the coordination of other similar activities by manufacturers, vendors, consultants, and utilities. [b-JRC, 2023] identifies and focuses on key issues and agreed solutions described in the best practices document.

DC certification according to EN 50600 is according to [b-TÜVIT] the first European-wide, transnational standard that provides comprehensive specifications for the planning, construction and operation of a DC with a holistic approach. It establishes requirements for construction, power supply, air conditioning, cabling and security systems, and specifies criteria for the operation of DCs. [b-EN 50600-4-x] relates directly to environmental control.

[b-ANSI/BICSI 002] on DC design and implementation best practices, covers all major internal systems. [b-ANSI/BICSI 002] not only lists what a DC requires, but also provides ample recommendations on the best methods of implementing a design to fulfil specific needs.

9.2 Other applicable environmental and sustainability standards

The ITU-T L.14xx-series provides overview and general principles of methodologies for assessing the environmental impact of ICTs. Within this family, the following Recommendations are of particular interest:

a) [b-ITU-T L.1410] on environmental life cycle assessments of goods, networks and services;

b) [b-ITU-T L.1420] on energy consumption in and GHG emissions from organizations;

c) [b-ITU-T L.1430] on ICT GHG and energy projects;

d) [b-ITU-T L.1440] on ICTs at city level;

e) [b-ITU-T L.1450] on the ICT sector.

ISO 9000 – Quality system [b-ISO QM]. The ISO 9000 family of quality management systems is a set of standards that helps organizations ensure they meet customer and other stakeholder needs within statutory and regulatory requirements related to a product or service.

[b-ISO 14001] sets out the criteria for an environmental management system and can be certified to. It maps out a framework that a company or organization can follow to set up an effective environmental management system. Designed for any type of organization, regardless of its activity or sector, it can provide assurance to company management and employees as well as external stakeholders that environmental impact is being measured and improved.

ISO 50001 [b-ISO EM] is based on the management system model of continual improvement also used for other well-known standards such as [b-ISO 9001] or [b-ISO 14001]. ISO 50001 provides a framework of requirements for organizations to develop a policy for more efficient use of energy, fix targets and objectives to meet the policy, use data to better understand and make decisions about energy use, measure the results, review how well the policy works, and continually improve energy management.

10 Data centres and the UN Sustainable Development Goals

From the 2015 launch of the 17 UN SDGs [b-UN], the potential influence that DCs can have on the local environment and social layers where this type of infrastructure is installed cannot be neglected. The impacts that DCs can have during their life cycle can be either negative or positive. An outline of DCs and their direct impact on eight SDGs for which connections have been identified follows.

Figure 8 illustrates the SDGs.

Figure 8 – UN Sustainable Development Goals [b-UN]

10.1 Goal 6 – Clean water and sanitation: Ensure availability and sustainable management of water and sanitation for all

With billions of people still lacking access to safe drinking water, sanitation, and hygiene and with 2.3 billion people living in water-stressed countries, water management is a critical issue that needs to be considered in all stages of the lifetime of a DC. As previously seen, due to a highly energy intensive and heat-generating industry, the issue of the availability and sustainable management of water is of the upmost importance.

There are two issues related to the consumption and availability of water in DC management. Firstly, DCs are ideally located in areas near to data end-users. This may be in water scarce, drought-prone areas in which DCs may be competing with the population for access to water coming from aquifers and surface sources. Like power plants, DCs in their server corridors use millions of litres of water for cooling as an alternative for electricity intensive mechanical chillers.

A way for DC operators to be on top of their water consumption is, as previously seen, by applying the indicator of water usage effectiveness that aids the DC administration to realize the impact that their DC is having in this environmental aspect.

Lately, some companies, like Google, have realized that the water being used for cooling systems is not required to be potable, thus setting up systems with local water and sewage treatment organizations in order to use grey water that is reused for evaporative cooling.

Increasing the temperature of the DC and the corridors housing the servers, seal the DC to minimize imbalances between the humidity and temperature. Raising the humidity of the DC or reusing rainwater are other best practices that can be applied in DCs, thereby reducing the need for cooling and consequent water consumption.

Related targets: 6.1, 6.3, 6.4, 6.5.

10.2 Goal 7 – Affordable and clean energy – Ensure access to affordable, reliable, sustainable, and modern energy for all

Goal 7 is probably the most relevant SDG for the operation of DCs. As previously outlined, DCs are highly energy intensive structures that, despite becoming more efficient, need to cope with the demand for data processing and storage.

The DCs can impact energy efficiency and the use of renewable energy in three ways: firstly, through its own impacts where DCs has to minimize their environmental load; secondly, by using the technology to enable solutions such as optimization of smart grids and smart buildings; thirdly, by participating actively in the energy market via PPAs or producing a renewable energy onsite.

The use of renewables with the installation of photovoltaic panels onsite or by PPAs on solar and wind power is proceeding rapidly. The industry is adopting these practices to be implemented especially in large, energy intensive DCs from bigger Internet and cloud service players.

Related targets: 7.2, 7.3.

10.3 Goal 9 – Industry, innovation, and infrastructure

SDG 9 aims to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". Specifically target 9c, access to ICTs and affordable Internet, can be enabled by DCs. This target that already aimed to significantly increase access to ICTs and provide universal and affordable access to the Internet in least developed countries by 2020 is directly connected to the accessibility of reliable data connections of the population and DCs play an important role in this. Moreover, the advent of Industry 4.0, ICT, and associated DCs, helps to foster innovation and make manufacturing industry more efficient and therefore more sustainable. With the COVID-19 crisis and global manufacturing decreasing, the increase of investment in research and development is essential in finding solutions for such crises and increasing the resilience of society.

Related targets: 9.1, 9.2, 9.4. 9.5.

10.4 Goal 11 – Sustainable cities and communities

Goal 11 has the objective of making cities and human settlements inclusive, safe, resilient, and sustainable. When thinking about cities and ICTs, smart cities might be the first association and in fact a city can be 'smart' only if it is sustainable.

The IoT, which will allow for smart cities to be powered by millions of connected devices and objects, as well as the coordination of interoperable technologies, is an area where DCs, and especially edge DCs will form an important part. Edge DCs are small facilities located close to the populations they serve, which deliver cloud-computing resources and cached content to end users. With this proximity and overall roll-out of smartphone technologies, ICT and DCs will deliver high levels of safety, resilience and sustainability.

This proximity will also help to act upon other issues like disaster risk reduction and the ability for cities to act on the needed adaptation for climate change, awareness of air quality, municipal waste management or the use of public spaces like the green areas. The same can be said for sustainable transport and the use of public transport. The ease and rapidity of IoT technologies will ultimately be able to aid in the use of public transport for all urban populations.

Related targets: 11.2, 11.3, 11.5, 11.6.

10.5 Goal 12 – Responsible consumption and production

For 2019, the amount of e-waste generated was estimated to 7.3 kg per capita, with only 1.7 kg per capita documented to be managed in an environmentally sustainable manner. E-waste generation has been expected to grow by 0.16 kg per capita annually to reach 9.0 kg per capita in 2030. The annual rate of growth in e-waste recycling over the past decade was 0.05 kg per capita, which will need to increase more than 10-fold if all of it is to be recycled by 2030 [b-Spaun].

Responsible consumption and production are also linked to ICT by enabling dematerialization and virtualization of products and services. Innovative ICT applications may enable sustainable production and consumption. The use of cloud computing, demand response and smart grids enabled by smart meters are several ways that can help individuals and companies reduce their consumption and allow energy companies to decrease their energy production. Nevertheless, these uses come with a price, as such technologies are energy consuming and may even experience rebound effects as people's behaviours change.

Related targets: 12.1, 12.2, 12.4, 12.5, 12.6, 12.a.

10.6 Goal 13 – Climate action

Goal 13 deals with the urgent need to combat climate change and its impacts. This goal aims to strengthen resilience and adaptive capacity to climate-related hazards, to integrate climate change measures into national and local strategies and planning, to improve education and finally to create awareness among human and institutional capacity for tackling climate change.

Goal 13 is one of the most important SDG goals for DCs, as they make up a highly energy intensive industry. To meet the goal, there is a need for the implementation of mitigation measures in all DCs that will ultimately result in cost reductions for their operators as a by-product.

The formulation of climate strategies in the DC industry in general and for individual structures is crucial, not only for the choice of local environment but also in terms of cost-effectiveness. The importance of location can be illustrated by bitcoin mining, which represents a great amount of energy consumption with little concern for energy efficiency other than the location of these servers as they are installed in such as cold desert areas.

The positive impact of DCs on climate change could for example be the potential of data processing to help science to act upon the information collected by satellites or sensors.

The implementation of voluntary schemes for the improvement of the efficiency of DCs may be one way of mitigating the impacts of the operation of DCs, along with traditional legislative schemes in place for energy intensive companies.

Related targets: 13.1, 13.2, 13.3.

10.7 Goal 14 – Life below water

Goal 14 – Life below water, relates to a specific by-product: the rejected water used for cooling some DCs. This has a high impact with hyperscale DCs located near lakes, rivers or even the sea, where the wastewater that has passed through the cooling system is returned to the environment. This operation comes, of course, with the cost of heating cooling water to temperatures higher than those in the natural environment. This can ultimately cause some disturbances in the fauna and flora in the region.

As a consequence, it is of special importance that the water being used for cooling, as well as that rejected, passes through a buffer system to cool it down to ambient temperature. This is done so that life below water remains unaffected.

Another best practice that can minimize the impact of DC cooling is the use of non-potable water, i.e., wastewater or actual seawater. This significantly reduces the volume used, with water being a natural resource, especially in drought-prone areas.

Related targets: 14.1, 14.2.

10.8 Goal 15 – Life on land

Together with the previous goal (SDG 14), goal 15 also connects with DCs through the site where it is implemented. For large DCs, the size of the area and the environmental impact in terms of landscape and the consumption of natural resources may be significant. SDG 14 aims to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and stop biodiversity loss. DC operators should use their best judgement when choosing a DC site, aiming to minimize the environmental impact of such land use.

Ideally, DCs should be installed in brownfield sites and impermeable areas where operators can then remediate the plot when the lifetime of the DC ends, instead of green-field sites, where the environmental impacts may be higher in terms of biodiversity and the impermeabilization of the land, thus potentiating water evaporation and desertification.

As good practice and due to the size of the implementation, hyperscale DCs are subject to the execution of an environmental declaration and an environmental impact assessment study prior to its approval and construction. This way, both the authorities and DC operators can assess and minimize the associated negative impacts during all stages of the life cycle of a DC, thereby protecting nearby habitats and combatting effects such as desertification.

11 Summary

The DC industry must address both the environmental dimension and the socio-economic challenges of local communities. It is without a doubt a highly impactful industry that contributes to the maintenance and growth of the binary world, via the IoT, cloud computing, data storage, artificial intelligence or machine learning.

The DC industry has made great progress with regards to energy efficiency and the annual energy efficiency achieved in the last several years has always more than compensated for the required computing capacity.

Frameworks like the Paris agreement and the SDGs establish measurable, mid- to long-term visions that could be supported by monitoring targets and indicators. To differentiate itself, it is of critical importance that the DC industry get together to formulate a long-term vision, based on the KPIs that it has in its possession. Institutional targets like net zero, zero waste, full circularity or reaching the tangent of a PUE of one or near to one should be the norm and not the exception.

The achievement of such sustainability goals is only possible when addressed throughout the DC life cycle, from the concept to design stage with the choice of using sustainable materials, to the construction phase making use of the least impactful ways of production, to operation by implementing energy and environmental management systems, metering and sub-metering its energy flows and finally in the end-of-life when it comes to give another destination to the IT products or the building itself. The implementation of voluntary schemes and standards may give an excellent perspective into managing all the life cycles of a DC.

An issue of great importance is the use and disposal of water used for the cooling DCs. In a time when water is becoming scarcer, DCs may be seen as increasing the water stress to ecosystems; thus the presence of water experts in a DC structure is essential. Moreover, it is of the utmost importance that metrics like water usage effectiveness work with other efficiency parameters like the PUE or CUE; all of these must be sought and also managed together.

Meeting the highest environmental standards for the surroundings of the DC is considered essential. The use of brown-field instead of green-field sites for DC implementation and occasionally using existing infrastructure is also highly recommended.

DCs also have a role to play in tenergy transition by aligning with the SDGs on sustainable and accessible renewable energy. Despite agreeing that the DC industry is highly energy intensive, it is also clear that efforts are being made by the industry (at least in hyperscale DCs) to make sure that electricity supplied is either coming from renewable sources or is produced onsite.

Appendix I

Some policies that incentivize the development of environmentally efficient data centres and the cloud

The Paris agreement and the UN SDGs need a global movement and actions by individuals, by organizations and every actor in modern society. Voluntary schemes and agreements have a role to play, but ultimately these efforts need an institutional push and leverage in order to drum up efforts from all parties.

Described below are some of the public policies that promote and facilitate a sustainable development which could provide guidance and directions to DC actors.

– **International level**

From the perspective of policy, the Paris agreement [b-UNFCCC] speaks of the vision of fully realizing both technology development and transfer for improving resilience to climate change and reducing GHG emissions. It establishes a technology framework to provide overarching guidance to the well-functioning technology mechanism. This mechanism means to accelerate technology development and transfer through its policy and implementation arms.

– **Europe**

The European Commission proposes the transformation of the EU economy and society to meet climate ambitions in their Green Deal [b-EC GD] with the circular economy action plan [b-EC CEAP] as one of its main components.

The European Commission adopted a set of proposals to make the EU's climate, energy, transport, and taxation policies fit for reducing net GHG emissions by at least 55% by 2030, compared to levels in 1990, and achieving climate-neutrality by 2050. Below are some of the legislative packages that help reaching this.

- *Energy efficiency directive* [b-EC EED]: In July 2021, a proposal for a new directive on energy efficiency was put forward. The proposal raises the level of ambition of the EU energy efficiency target and makes it binding. The revised directive also requires EU countries to collectively ensure an additional reduction of energy consumption of 9% by 2030 compared to the 2020 reference scenario projections.
- *Energy performance of buildings directive* [b-EC EFBD]: The energy performance of buildings directive is the European Union's main legislative instrument aiming to promote the improvement of the energy performance of buildings within the community setting binding emission reduction targets.
- *Zero pollution action plan* [b-EC ZPAP]: The zero-pollution vision for 2050 is for air, water and soil pollution to be reduced to levels that are no longer considered harmful to health and natural ecosystems that respect the boundaries with which our planet can cope, thereby creating a toxic-free environment. Corresponding 2030 targets include quantitative targets for air, water and soil quality, waste reduction and for share of ecosystems and people impacted.

– **Asia**

Other larger players in the global panorama have also declared their commitments for the achievement of the Paris agreements. The People's Republic of China has recently declared its intentions to be a carbon neutral state by 2060, while the Republic of Korea has vouched for carbon neutrality by 2050 as per the Paris agreement.

Japan has formulated a new strategy named "beyond-zero carbon" [b-METI], which aims to promote innovation and technology as the agents of change in tackling the challenges of global warming; promote green finance to support the development of innovation and new technologies and support greater international cooperation for business-led adoption of innovative green technologies.

– **Others**

The US long-term strategy was submitted to the UNFCCC in November 2021 officially committing the country to net zero emissions by 2050 at the latest.

Canada [b-Canada, 2021] has vouched for the achievement of reaching net zero emissions by 2050. The Canadian *Net-Zero Emissions Accountability Act* became law 2021-06-21 to formalize Canada's target to achieve net-zero emissions by the year 2050, and establish a series of interim emissions reduction targets at 5 year milestones towards that goal. It will also require a series of plans and reports to support accountability and transparency and ensure Canada hits all of its milestones on the way to its goal in order to achieve a prosperous net-zero economy by the year 2050.

Bibliography

[b-ITU-T L.1302] Recommendation ITU-T L.1302 (2015), *Assessment of energy efficiency on infrastructure in data centres and telecom centres*.

[b-ITU-T L.1400] Recommendation ITU-T L.1400 (2011), *Overview and general principles of methodologies for assessing the environmental impact of information and communication technologies*.

[b-ITU-T L.1410] Recommendation ITU-T L.1410 (2014), *Methodology for environmental life cycle assessments of information and communication technology goods, networks and services*.

[b-ITU-T L.1420] Recommendation ITU-T L.1420 (2012), *Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organizations*.

[b-ITU-T L.1430] Recommendation ITU-T L.1430 (2013), *Methodology for assessment of the environmental impact of information and communication technology greenhouse gas and energy projects*.

[b-ITU-T L.1440] Recommendation ITU-T L.1440 (2015), *Methodology for environmental impact assessment of information and communication technologies at city level*.

[b-ITU-T L.1450] Recommendation ITU-T L.1450 (2018), *Methodologies for the assessment of the environmental impact of the information and communication technology sector*.

[b-ITU-T X.1053] Recommendation ITU-T X.1053 (2017), *Code of practice for information security controls based on ITU-T X.1051 for small and medium-sized telecommunication organizations*.

[b-ITU-T Y.3500] Recommendation ITU-T Y.3500 (2014), *Information technology – Cloud computing – Overview and vocabulary*.

[b-ITU IW] ITU (2020), *Internet waste: A thought paper for International E-Waste Day 2020*. 35 pp. Geneva/Brussels: International Telecommunication Union/WEEE Forum, Available [viewed 2023-01-17] at: https://www.itu.int/dms_pub/itu-d/opb/str/D-STR-INTERNET_WASTE.01-2020-PDF-E.pdf

[b-ITU terms] ITU (Internet). *Terms and definitions*. Geneva: International Telecommunication Union. Available [viewed 2023-01-17] at: https://www.itu.int/br_tsb_terms/

[b-EN 50600-4-x] EN 50600-4 (all parts): *Information technology – Data centre facilities and infrastructures – Part 4-x*.

[b-ISO EM] ISO (Internet). *ISO 50001: Energy management*. Geneva: International Organization for Standardization. Available [viewed 2023-01-19] at: https://www.iso.org/iso-50001-energy-management.html

[b-ISO QM] ISO (Internet). *ISO 9001 and related standards: Quality management*. *Geneva*: International Organization for Standardization. Available [viewed 2023-01-19] at: https://www.iso.org/iso-9001-quality-management.html

[b-ISO 9001] ISO 9001:2015, *Quality management systems – Requirements*.

[b-ISO 14001]	ISO 14001:2015, *Environmental management systems – Requirements with guidance for use*.
[b-ISO/IEC 30134-1]	ISO/IEC 30134-1:2016, *Information technology – Data centres – Key performance indicators – Part 1: Overview and general requirements*.
[b-ISO/IEC 30134-2]	ISO/IEC 30134-2:2016, *Information technology – Data centres – Key performance indicators – Part 2: Power usage effectiveness (PUE)*.
[b-ISO/IEC 30134-3]	ISO/IEC 30134-3:2016, *Information technology – Data centres – Key performance indicators – Part 3: Renewable energy factor (REF)*.
[b-ISO/IEC 30134-4]	ISO/IEC 30134-4:2017, *Information technology – Data centres – Key performance indicators – Part 4: IT equipment energy efficiency for servers (ITEEsv)*.
[b-ISO/IEC 30134-5]	ISO/IEC 30134-5:2017, *Information technology – Data centres – Key performance indicators – Part 5: IT equipment utilization for servers (ITEUsv)*.
[b-ISO/IEC 30134-6]	ISO/IEC 30134-6:2021, *Information technology – Data centres key performance indicators – Part 6: Energy reuse factor (ERF)*.
[b-ISO/IEC 30134-7]	ISO/IEC 30134-7:2023, *Information technology – Data centres key performance indicators – Part 7: Cooling efficiency ratio (CER)*.
[b-ISO/IEC 30134-8]	ISO/IEC 30134-8:2022, *Information technology – Data centres key performance indicators – Part 8: Carbon usage effectiveness (CUE)*.
[b-ISO/IEC 30134-9]	ISO/IEC 30134-9:2022, *Information technology – Data centres key performance indicators – Part 9: Water usage effectiveness (WUE)*.
[b-ANSI/BICSI 002]	ANSI/BICSI 002-2019, *Data center design and implementation best practices*.
[b-Bertoldi, 2017]	Bertoldi, P., Avgerinou, M., Castellazzi, L. (2017). *Trends in data centre energy consumption under the European Code of Conduct for Data Centre Energy Efficiency*, EUR 28874 EN. Luxembourg: Publications Office of the European Union, doi:10.2760/358256
[b-Bertoldi, 2018]	Bertoldi, P., Diluiso, F., Castellazzi, L., Labanca, N., Ribeiro Serrenho, T. (2018), *Energy Consumption and Energy Efficiency Trends in the EU-28 2000-2015*, EUR 29104 EN. 175 pp. Luxembourg: Publications Office of the European Union, Available [viewed 2023-01-17] from: https://publications.jrc.ec.europa.eu/repository/handle/JRC110326
[b-BREEAM]	BREEAM (2021), *Community of passionate influencers improving the built environment*. Watford: Building Research Establishment. https://www.breeam.com/ (Accessed in September 2021).

[b-Canada] Government of Canada (2022). *Net-zero emissions by 2050*. Ottawa, ON: Government of Canada. Available [viewed 2023-01-20] at: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html.

[b-CBRE] CBRE (2021). *The mystery impact of data centres on local economies revealed*. https://www.areadevelopment.com/data-centres/Data-Centres-Q1-2015/impact-of-data-centre-development-locally-2262766.shtml (Accessed in September 2021).

[b-EC CEAP] European Commission (Internet). *Circular economy action plan: The EU's new circular action plan paves the way for a cleaner and more competitive Europe*. Brussels: European Commission. Available [viewed 2023-01-19] at: https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

[b-EC EED] European Commission (Internet), *Energy efficiency directive*. Brussels: European Commission. Available [viewed 2023-01-19] at: https://ec.europa.eu/energy/topics/energy-efficiency/targets-directive-and-rules/energy-efficiency-directive_en

[b-EC GD] European Commission (Internet). *A European green deal: Striving to be the first climate-neutral continent*. Brussels: European Commission. Available [viewed 2023-01-19] at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#highlights

[b-EC EPBD] European Commission (Internet). *Energy performance of buildings directive*. Brussels: European Commission. Available [viewed 2023-01-19] at: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[b-EC ZPAP] European Commission (Internet). *Zero pollution action plan; Towards zero pollution for air, water and soil*. Brussels: European Commission. Available [viewed 2023-01-19] at: https://ec.europa.eu/environment/strategy/zero-pollution-action-plan_en

[b-Google, 2020] Google (2020). *Google environmental report 2020*. Mountain View, CA: Google. 82 pp. Available [viewed 2023-01-17] at: https://www.gstatic.com/gumdrop/sustainability/google-2020-environmental-report.pdf

[b-IEA] IEA (2020), Paris: International Energy Agency. https://www.iea.org/reports/data-centres-and-data-transmission-networks (Accessed in July 2021).

[b-Ipsen] Ipsen, H. (2018), *Catching the cloud and pinning it down: The social and environmental impacts of data centres* [Thesis]. New York, NY: Syracuse University. Available [viewed 2023-01-18] at: https://surface.syr.edu/thesis/211

[b-JRC, 2015] Talens Peiró, L., Ardente, F. (2015). (2015). *Environmental footprint and material efficiency support for product policy – Analysis of material efficiency requirements of enterprise servers*, JRC science and policy report. Luxembourg: Publications Office of the European Union. 110 pp. Available [viewed 2023-01-17] at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC96944/lb-na-27467-en-n%20.pdf

[b-JRC, 2021] European Commission, Joint Research Centre (2021), *Code of Conduct for Data centres Energy Efficiency*.

https://e3p.jrc.ec.europa.eu/communities/data-centres-code-conduct (Accessed in May 2021).

[b-Masanet, 2020] Koomey, J., Smith, S., Nuoa Lei, N., Shehabi, A., Masanet, E. (2020). Recalibrating global data centre energy-use estimates. *Science*, **367**(6481), pp. 984-986. https://doi.org/10.1126/science.aba3758

[b-Menon] Grünfeld, L., Wang Gierløff, C., Stemland Eide, L. (2017). *Economic impact of a hyperscale data centre establishment in Norway, 2017*, Menon-Publication No. 39/2017. 4 pp. Oslo: Menon Economics. Available [viewed 2023-01-18] at: https://www.statkraftdatacentersites.com/globalassets/9-statkraft-datacentres/documents/menon_economic-impact-report_english.pdf

[b-METI] METI (Internet). *Japan's roadmap to "beyond-zero" carbon*. Tōkyō: Ministry of Economy, Trade and Industry. Available [viewed 2023-01-20] at: https://www.meti.go.jp/english/policy/energy_environment/global_warming/roadmap/index.html

[b-Mytton] Mytton, D. (2021). Data centre water consumption. *npj Clean Water* **4**, 11. https://doi.org/10.1038/s41545-021-00101-w

[b-Nortek] Holla, K. (2020), *Waste heat utilization is the data center industry's next step toward net-zero energy*. O'Fallon, MO: Nortek Data Center Cooling. Available [viewed 2023-01-17] at: https://www.datacenterfrontier.com/voices-of-the-industry/article/11428787/waste-heat-utilization-is-the-data-center-industrys-next-step-toward-net-zero-energy

[b-Oxford Economics] Levine, D, editor (2018), *Google data centres: Economic impact and community benefits*. Oxford: Oxford Economics. 39 pp. Available [viewed 2023-01-18] from: https://www.oxfordeconomics.com/recent-releases/d8d830e4-6327-460e-95a5-c695a32916d9

[b-Ratka] Ratka, S., Boshell, F. (2020). The nexus between data centres, efficiency and renewables: A role model for the energy transition. *energypost.eu*. Available [viewed 2023-01-17] at: https://energypost.eu/the-nexus-between-data-centres-efficiency-and-renewables-a-role-model-for-the-energy-transition/

[b-Reddy] Reddy, V.D., Setz, B., Rao, G.S.V.R.K., Gangadharan, G.R., Aiello, M. (2017). Metrics for sustainable data Centres. In: *IEEE Trans. Sust. Comput.* **2**(3), pp. 290-303. doi: 10.1109/TSUSC.2017.2701883

[b-Schneider Electric] Schneider Electric (2017), *The different technologies for cooling data centres*, White Paper 59 Rueil-Malmaison: Schneider Electric. https://download.schneider-electric.com/files?p_Doc_Ref=SPD_VAVR-5UDTU5_EN (Accessed in September 2021).

[b-Spaun] Spaun, S., Papsch, F., Friedle, R., Dankl, C., Bauer, C. (2021), A path towards climate neutral production of cement in austria via a new circular economy. In: Schnitzer, H., Braunegg, S. (editors). *Proceedings of the 20th European Roundtable on Sustainable Consumption and Production*, pp. 553-566. Available [viewed 2023-01-18] at: https://diglib.tugraz.at/download.php?id=612dfa88c5513&location=browse

[b-TÜVIT] TÜVIT (Internet). *Data center certification according to EN 50600*. Essen: TÜV Nord Group. Available [viewed 2023-01-19] at: https://www.tuvit.de/en/services/data-centers-colocation-cloud-infrastructures/din-en-50600/

[b-UN] Department of Economic and Social Affairs: Sustainable Development (Internet). *The 17 goals*. New York, NY: United Nations, Available [viewed 2023-01-17] at: https://sdgs.un.org/goals

[b-UNEP terms] Life Cycle Initiative (2022). *Glossary of life cycle terms*. Paris: United Nations Environmental Programme. Available [viewed 2023-01-17] at: https://www.lifecycleinitiative.org/resources/life-cycle-terminology-2/

[b-UNFCCC] United Nations Climate Change (Internet). *The Paris Agreement: What is the Paris Agreement?* Bonn: United Nations Framework Convention on Climate Change. Available [viewed 2023-01-19] at: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[b-UNU/UNITAR] Forti, V., Baldé C., P., Kuehr, R., Bel, G. (2020). *The global e-waste monitor 2020: Quantities, flows and the circular economy potential*. 120 pp. Bonn/Geneva/Rotterdam: United Nations University (UNU) + United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme/ International Telecommunication Union/International Solid Waste Association. Available [viewed 2023-01-18] at: https://www.itu.int/en/ITU-D/Environment/Documents/Toolbox/GEM_2020_def.pdf

[b-USGBC] USGBC (2021), *Building design and construction: Data centers*. Washington, DC: US Green Building Council. Available [viewed 2023-01-18] at: https://www.usgbc.org/discoverleed/certification/bd-c-data-centers/

[b-WGBC] WGBC (2019), *Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon*. London: World Green Building Council. https://www.worldgbc.org/sites/default/files/WorldGBC_Bringing_Embodied_Carbon_Upfron.pdf, (Accessed in October 2021).

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	**Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant**
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling, and associated measurements and tests
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities
Series Z	Languages and general software aspects for telecommunication systems

Published in Switzerland
Geneva, 2023