Smart life and sustainable development: a comparative analysis on energy and water efficiency in China and the EU

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Abstract
Smart life relies on huge volumes of data analysis, which makes data centers become important infrastructure in smart city areas. Nowadays, data centers are constructed in many countries and have become increasingly large electricity consumers. The consumption of electricity is caused not only by the servers of data centers but also by the cooling systems. Meanwhile, data centers also demand water - cooling methods, which result in water consumption. As for sustainable development, water and energy consumption are huge challenges. Laws and rules are necessary for utilizing efficiently relevant sources. This paper will analyze China and the European Union (EU) as two examples of jurisdictions to compare how the governments regulate the construction of data centers to implement the thrift of electricity and water. In China, provinces and cities established diverse regulations based on their different natural and climate conditions, thus there is not a uniform model for the implementation in the country. In the EU, the amendment of Energy Efficiency Directive seeks to establish common policies. The difference of rules in these two jurisdictions reflects that China and the EU have their own principles and objectives: China attempts to balance the demand of developing smart city infrastructures and the consumption on natural resources, but the EU has strong ambition on low carbon emission in the whole Union. However, the two jurisdictions still have a common goal to maximize the efficiency of water and electricity consumption which is a fundamental issue for accelerating the transition towards sustainability.

Keywords: Sustainability, data center, cooling market, Best practices, Energy Efficiency Directive.

1. Introduction

Increased usage of ICT is a critical component of social progress and smart living; therefore, data centres are consequently becoming an increasingly vital component of modern infrastructure. They have evolved into the transactional backbone of contemporary civilization and the global digital economy. Data centres are projected to have the fastest rising energy consumption and carbon footprint in the whole ICT industry, owing to technical breakthroughs such as cloud computing and the rapid expansion of Internet service use.

According to a report, in the EU, from 2010 to 2018 data centre energy consumption increased by 42% and is forecast to further increase by 28.2% by 2030, representing about 3.2% of the EU final electricity demand [1]. This is likely to increase with digitisation and emerging technologies such as artificial intelligence, the Internet of Things and blockchain. Despite this significant grow, the Commission predicts that energy consumption will only rise from 58 TWh in 2015 to 69.5 TWh in 2030. It is expected here that gains in energy efficiency will be significant as a result of virtualization and enhanced chip performance, limiting the rise in power usage to a minimum, and that the average power usage effectiveness (PUE) will slowly decline from 2.0 to 1.5 over the same period [1].

China has taken the lead over global peers in data center construction, with more enterprises looking to scale up their data centers to ensure reliability and stability of data services. With the rapid development of 5G, the IoT, artificial intelligence, industrial internet and the commercial application of these new cutting-edge technologies, the demand for data processing is increasing, which has sped up the construction of data centers across the nation. However, the investment in establishing data centers is enormous and these centers consume a large amount of electricity, which causes carbon emissions and environmental pollution.

In China the consumption of electricity by data center keeps constant growth from 2010 to 2020. According to the Energy conservation retrofit and practical case of data center by Green World Low-carbon Economy & Technology Center (GWLETC), the electricity consumption of data center occupied 1%-2% of the total national electricity consumption [2]. The chart below shows the increasement of data centers' consumption of electricity [2]. Thus, China's data centers accounted for 2.71% of the national electricity consumption in 2020 and are expected to account for 4.05% in 2025 [3].

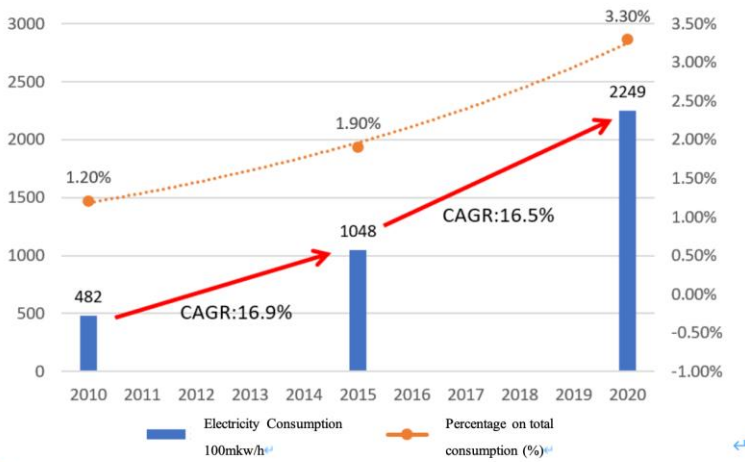

Fig. 1. 2010-2020 China Data Centre Electricity Consumption and Growth Rate.
Source: GWLETC's report citing DCMAP, China Information Security Measurement and Assessment Centre (CISMAC), China Electronic Energy Conservation Technology Association Data Centre Energy Conservation Technical Committee.

GWLETC's report also pointed out that the consumption of electricity has three streams: servers and software; cooling system; and electrical system. Among these three streams, electrical system has the smallest proportion, only 18%. Server and software occupied 42%, and cooling system is of 40%. [2] Even though the cooling system is considered an "assistant system", which do not provide the main function of data centers, the consumption of electricity is still huge. Thus, most of the energy in data centers is used to power servers, but the huge facilities also produce heat and need to be cooled. This requires either energy when using traditional air cooling, or water when servers are cooled by evaporating water, which is more energy efficient.

The EU authorities have been entering into a debate about data centres demands, that is not new, but is getting increasingly urgent as climate change causes more Europeans to experience considerably hotter and drier summers. Reducing the energy consumption of ICT, particularly data centres, is a critical step towards meeting the EU's ambitious climate objectives, which call for a 55% decrease in overall GHG emissions by 2030 compared to 1990 levels. If powered by green electricity, with great energy efficiency, and as variable loads, the data centre business might be a driving force in the shift to renewable energy sources.

China acknowledges that the digital economy relies on data centers. Developing data center means providing fundamental support to the economy thus the government itself promotes such model. The higher requirements on developing digital economy raise questions on how to maintain this development with limited sources, reduce the costs, and solve the problems caused by data center construction in big cities. Meanwhile, China also has its goal on low carbon emission and energy and water efficiency. The central government made a three-step proposal which aims to decrease 18% of carbon emission by 2025 compared to 2020 levels, 65% of carbon emission by 2030 compared to 2005 levels, and reach carbon neutrality by 2060.

2. Data centers legal definition

Any policy measure requires a precise description of the topic within its area of action, in this case, data centres, before it can be developed and implemented. The proposed definition must be explicit, provide clear boundaries that include all data centres within the scope, and be compatible with existing EU regulations.

According to Regulation (EC) 1099/2008 and Regulation (EU) 2022/132 [4] a data centre is defined as a structure or a group of structures used to house, connect and operate computer systems/servers and associated equipment for data storage, processing and/or distribution, as well as related activities [4]. The revised Energy Efficiency Directive (Directive (EU) 2023/1791) (EDD) defining data centers also make reference to the definition provided in Regulation (EC) No 1099/2008 [5].

A structure can consist of multiple buildings and/or spaces with specific functions to support the primary function. Within a larger structure or building, the boundaries of the structure or space considered the data centre, which comprises the information and communication technology equipment and accompanying environmental controls, might be established [6].

Associated equipment for related activities means all the facilities and infrastructures for power distribution and environmental control together with the necessary levels of resilience and security required to provide the desired service availability.

The definition of a data centre provided in the EN50600 Series of standards developed by the European Committee for Electrotechnical Standardization (CENELEC) is used by several standardisation organisations (ISO/IEC, ETSI, CEN-CENELEC) [7] and is more detailed. EN 50600 defines data centre as a structure, or group of structures, dedicated to the centralised accommodation, interconnection and operation of information technology and network telecommunications equipment providing data storage, processing and transport services together with all the facilities and infrastructures for power distribution and environmental control together with the necessary levels of resilience and security required to provide the desired service availability [7].

The definitions from Regulation (EU) 2022/132 and EN 50600 were generally supported by EU stakeholders, considered as based on international standards and useful for policy harmonisation, and adequate to capture any building, structure or container used as data centre, even small server rooms. However, the ability of the definition to include some decentralised data centres was questioned [6].

Unlike EU regulations, which provide detailed definitions, Chinese law does not define data center directly but provides a concept of "data center service" which contains the definition of data center. According to the Telecommunications Catalogue (Class B11), issued by the Ministry of Industry and Information Technology (MIIT), data center is defined as facilities to provide placement, agent maintenance, system configuration and management services for Internet or other network-related equipment, such as database systems, servers, storage space and other application services [8].

3. The technical potential for energy-efficient data centres

The cooling system is one of the most important elements of the infrastructure to guarantee normal operations of data centers. From the perspective of technology, there are two method of cooling and accordingly there are two type of data centers. In Habibi Khalaj and Halgamuge's research paper, the authors listed air-cooled data center and liquid-cooled data center as such two types [9]. In air-cooled data center scenarios, there were five levels of cooling: chip, server, reck, plenum and room respectively [9]. There is no doubt that cooling tasks should be completed from all dimensions, but a good plan on how to choose, arrange and place relevant devices and machines products will help to increase the efficiency of cooling. A basic mechanism of the room-level air-cooling technology under the raised-floor design is provided [10].

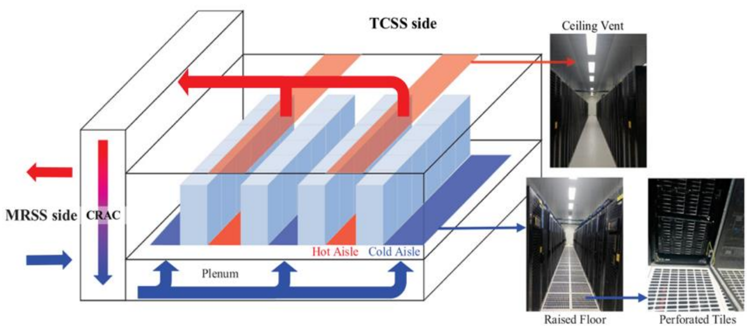

Fig.2. The basic mechanism of the room-level air-cooling technology under the raised-floor design.
Source: Zhang et al., 'A Survey on Data Center Cooling Systems'.

A good cooling designed server is certainly better than other ones in composing a data center. However, this does not change the question that cooling system still needs energy and other resources. An efficient cooling system may consume more electricity, which decreases the efficiency of energy usage. Khalaj and Halgamuge even admitted that air cooling is not efficient because air itself is of low density and low heat removal capacity This means energy consumption will increase if the cooling method is not efficient. According to Saini and Webb, the limitation will be more tangible with the emergence of high-performance microprocessors in servers, which will dissipate more than 100 W/cm^2 heat fluxes inside DC, where the maximum capacity of air heat removal is around 37 W/cm^2 [9] [11].

Liquid cooling method is considered to be more efficient [9]. It is classified as indirect and direct liquid cooling depending on whether the heat source and liquid coolant have direct contact. [9] Traditionally, cold plates and water-blocks are used [9]. In a typical indirect liquid cooling scenario, liquid coolant is delivered to racks, servers and chips, and other parts of the data center is through air cooling. The hot water stream carries heat out of rooms and expulse it into the atmosphere through chillers. The working principle is shown below [9]:

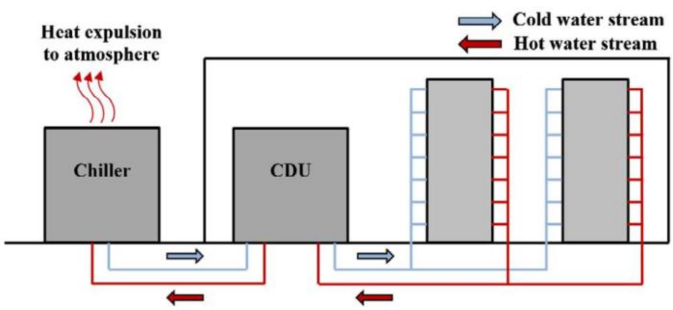

Fig.3. Typical schematic of indirect liquid cooling system.
Source: Habibi Khalaj and Halgamuge, 'A Review on Efficient Thermal Management of Air- and Liquid-Cooled Data Centers'.

The indirect liquid cooling method brings the consumption of coolant, including water. Particularly, if water is used as coolant, the consumption is not limited in energy. The consumption on water helps reducing the consumption on electricity because the liquid coolant is more efficient than air [9]. Other liquid coolants may also be used, for example, liquid nitrogen. In such a scenario, the consumption of electricity will increase because liquid coolants need to be switched back to liquid after the expulse the heat to the atmosphere. Water coolant can rely on the direct supply of cold water, but other liquid coolant must be used in cycle, which creates more electricity consumption. Direct liquid cooling is to enable liquid coolants to have direct contact with servers or chips. However, the main advantage is the adaptability of this method, in another word, how to immerse those electronical components in such liquids [9]. Thus, data centers are considered to consume water across two main categories: indirectly through electricity generation (traditionally thermoelectric power) and directly through cooling [12].
While liquid cooling systems are more difficult to install and operate, they can provide more effective cooling than air cooling, extending the life and performance of computer components. As a result, water is increasingly being acknowledged as a possible issue for

data centre operators, with a declining supply potentially affecting data access continuity.

Deployment of cooling systems can result in significant amounts of water consumption. According to reports, it is considered that a data centre uses 26 million litres of water each year, on average, per megawatt of data centre power. Based on this figure, and assuming that 20% of all the existing European data centres are using liquid cooling systems, the amount of water usage by data centres would reach 43.2 billion litres annually.

Before investing in a data centre, developers, operators, and investors must carefully consider water availability and security. According to the most recent Aquastat statistics, the Nordic countries are among the least vulnerable to water scarcity. They benefit from abundant domestic water supplies per capita. Ireland, France, and Italy have comparatively good renewable water resources per population, as well as a low dependant ratio (less than 10%).

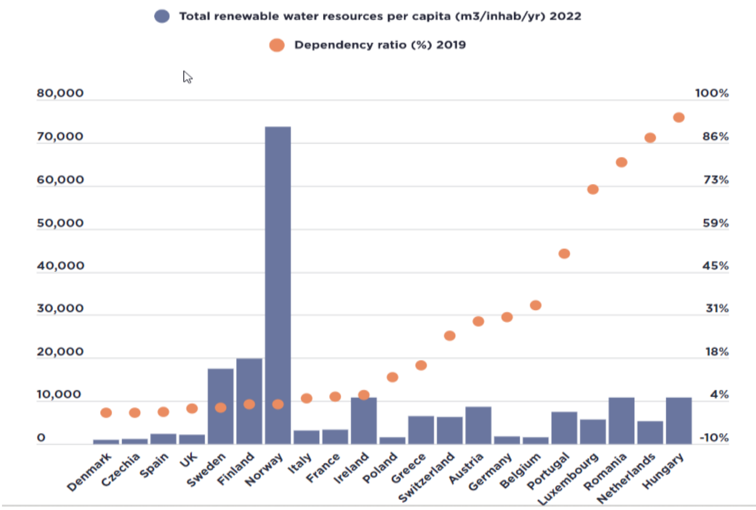

Fig. 4. Total renewable water resources in the EU Member States in 2022
Source: Savills Research

4. Problems related to data centers' high consumptions of electricity and water

The high demand of electricity and water makes the cost of data center operation also keep on high level. The operators of data centers seek different methods to decrease the costs. Besides making a better design of cooling system and using high-efficiency devices, data centers may choose to construct their infrastructures in special regions. Geographical elements for the choice of data center locations include climate, price of energy and other sources, water supply, etc. For instance, Facebook established its Lulea data center in northern Sweden, locating just 70 miles south of the Arctic Circle [13]. Facebook aims to use cold air in this region as coolant and increase the efficiency of cooling system. Alibaba and Microsoft establish their data center underwater [14]. Besides, US companies also seek to put their data center in Latin America because land, power, and water are expected to be cheaper [15]. The same goes for Chinese companies who seek to put their data center in Guizhou or Inner Mongolia where electricity, water and other elements are cheaper than in regions like Beijing or Shanghai.

The problem of cost brought by high consumption of natural source is obvious. The active behaviors of Internet companies show that the problem is quite serious and even big companies cannot afford it. Even though the statistics of water and electricity consumption already provide enough data, companies' behaviors prove that the shortage of relevant sources may approach. The cheap cost of electricity and water in some regions may be affordable for Internet companies, but this may allow them to be less diligent in thrift of relevant sources. Meanwhile, the concentrated construction of data centers may bring other problems in urban areas, for example, they will compete with citizens daily use of water and electricity, which bring heavy pressure on big city management. Besides, the heat expulsed to the atmosphere also bring environment problems because of heat waste and carbon emission caused by cooling system.

5. Energy efficiency policies in the EU

The EU has dual ambitions to become greener and more digital. It wants 75 % of European companies to use cloud services by 2030 and at the same time is aiming for "climate-neutral, highly energy-efficient and sustainable" data centers. To meet this goal, the Commission will rely on a mix of existing instruments, reviews of existing legislation and new initiatives.

Existing instruments include:

- The European Green Deal; [16]
- European Climate Law (Regulation (EU) 2021/1119); [17]
- The Ecodesign Regulation on servers and data storage products; [18]
- The revised Energy Efficiency Directive; [9]
- The EU Code of Conduct on Data Centre Energy Efficiency; [19]
- The EU Green Public Procurement criteria for data centres, server rooms and cloud services [20].

The Commission is also linking energy efficient data centres to policy and funding initiatives, notably through:

- The Taxonomy Regulation [21] and its Delegated Act adopted in July 2021, which sets the framework for investments to be qualified as sustainable and whose delegated act is currently under finalisation, has a section on data centres;
- Its funding programmes: Horizon Europe, Connecting Europe Facility 2, Digital Europe programme, InvestEU and the Recovery and Resilience Facility will support the deployment of an innovative, green and secure cloud.

In that context, the Commission, in its communication of February 19, 2020, on "Shaping Europe's digital future", highlighted the need for highly energy-efficient and sustainable data centres and transparency measures for telecoms operators as regards their environmental footprint. Furthermore, the possible increase in industry's energy demand that may result from its decarbonisation, particularly for energy intensive processes, should also be taken into account.

One of the primary EU policy initiatives for energy efficiency is the Ecodesign Regulation on servers and data storage products [18]. Ecodesign requirements have as aim to harmonise energy consumption and resource efficiency requirements for servers and data storage products throughout the Union, for the internal market to operate better and in order to improve the environmental performance of those products.

According to the recital 6 of the Regulation, the annual energy consumption related to servers directly is expected to be 48 TWh in 2030, which increases to 75 TWh when the annual energy consumption related to infrastructure (e.g. cooling systems and uninterruptible power supply systems) is also included. The preparatory study shows that use-phase energy consumption by servers and data storage products can be significantly reduced [18]. Under the Ecodesign Regulation is set minimum mandatory efficiency requirements for products allowed on the European market. The regulations for data centre servers and storage devices will include thresholds for certain components and for idle power consumption, as well as material efficiency requirements. They will also force manufacturers to provide information on the energy performance of equipment.

As a part of the "Fit for 55" package and the REPowerEU plan, the revised Energy Efficiency Directive (EED) [22] adopted in September 2023, includes new obligations that target data centres. It offers an ambitious roadmap aimed at accelerating Europe's energy efficiency initiatives. The EED must be transposed by EU member states by May 15, 2024.

The EED embeds in the Article 3 the "energy efficiency first" principle, and states that energy supply and demand be made more efficient, by cost-effective end-use energy savings, demand-response initiatives and more efficient conversion, transmission and distribution of energy [22]. In accordance with the energy efficiency first principle, Member States shall ensure that energy efficiency solutions are assessed in planning, policy and major investment decisions of a value of more than EUR 100 000 000each or EUR 175 000 000 for transport infrastructure projects, relating to (a) energy systems and (b) non-energy sectors, where those sectors have an impact on energy consumption and energy efficiency such as buildings, transport, water, information and communications technology (ICT), agriculture and financial sectors.

The directive direct implications for data centre operators and developers in Europe includes:

1. Reduction targets: A goal for the EU to achieve an 11,7% reduction in final energy consumption by 2030, with each Member State required to present its indicative national contribution. This target aligns with the EU Green Deal's objective to reduce carbon emissions by 55% within the same timeframe.
2. Mandatory reporting for large data centres: Data centres that have a capacity larger than 500kW are required to report their energy efficiency figures as of 15 May 2024. It's a significant move, recognizing that larger facilities, due to their scale, can have a substantial impact on overall energy consumption trends in the region. This mandatory reporting requirement intends to make these data centres more efficient in their operations. Article 3 (2) of the EED, imposes an obligation on the European Commission to carry out an assessment of the thresholds 500kW by 11 October

2027, with the aim of downward revision, taking into account possible developments in the economy and in the energy market. The Commission shall, by 11 October 2028, submit a report to the European Parliament and to the Council, followed, where appropriate, by legislative proposals [22].

3. Reporting requirements: One of the many parts of the directive that stand out to data centre architects and operators across Europe is its emphasis on measuring data centre energy performance. To support sustainable development in the ICT sector, Article 12 of the revised EED asks data centres to make information about their energy performance publicly available. These reporting requirements would apply to all DCs, old and new, whose IT installed power demand is above a threshold. In the Annex VII of the EED "Minimum requirements for monitoring and publishing the energy performance of data centres" are enumerated minimum information that shall be monitored and published with regard to the energy performance of data centres referred to in Article 12: a) the name of the data centre, the name of the owner and operators of the data centre, the date on which the data centre started its operations and the municipality where the data centre is based; b) the floor area of the data centre, the installed power, the annual incoming and outgoing data traffic, and the amount of data stored and processed within the data centre; c) the performance, during the last full calendar year, of the data centre in accordance with key performance indicators about, inter alia, energy consumption, power utilization effectiveness (PUE), temperature set points, waste heat utilisation, water usage and use of renewable energy, using as a basis, where applicable, the CEN/CENELEC EN 50600-4 "Information technology – Data centre facilities and infrastructures", until the entry into force of the delegated act adopted pursuant to Article 33(3) by the European Commission. A database at the European Union level will be established with the responsibility of collecting and disseminating information on data center energy performance. This action reflects the growing significance of data centers in the EU's future energy-efficiency goal.
4. Evolving performance standards: The EU will analyze the data it collects in 2024 and issue a report in 2025. EU regulations will set sustainability performance standards for data centres by 2025, a measure welcomed by countries with large data centre footprints such as Ireland and Germany. By examining this data, the EU will be better positioned to refine performance standards, possibly introducing minimum requirements or specific labeling to guide end-users and stakeholders.
5. Exceptions and performance requirements: While there are specific exemptions, such as data centres utilized for a country's defense, the Directive in Article 12 (4) encourages larger facilities (above 1MW) to adopt the best practices as outlined in the European Code of Conduct on Data Centre Energy Efficiency. This balanced approach ensures that while there's flexibility, there's also a strong nudge towards industry-leading standards.

The European Code of Conduct for Data Centres (EU DC CoC) is a voluntary initiative set up by the Joint Research Centre (JRC) in response to the increasing energy consumption in data centres and the subsequent environmental, economic and energy supply security impact that arises from it [19]. It was created to encourage and guide data centre operators and owners in cost-effectively reducing energy consumption without compromising the mission-critical function of these facilities. EU DC CoC aims to achieve considerable energy savings in this power-hungry industry by enhancing understanding of energy consumption within data centres, promoting awareness, and advocating energy-efficient best practises.

The EU DC CoC establishes ambitious voluntary standards for organisations that decide to become members as participants (data centre operators). Parties also can join the CoC as endorsers, who are other actors in the sector, such as vendors, consultants, customers, industrial associations or utility companies. Participants have a responsibility to monitor and report the energy efficiency of their data centre to the JRC on a yearly basis, as well as to demonstrate continuous progress over time. Endorsers agree to promote the CoC and must report on their activity. In addition to the reporting mechanism, parties identify and focus on significant concerns and agreed-upon solutions, as detailed in the Best Practises document [23]. These Best practices are a set of standards describing energy-efficient solutions in data centre design and operation. They cover a wide range of design and operational factors relevant to energy efficiency in data centres, such as utilization, management and planning, IT equipment and services, cooling, power equipment, building design, and monitoring. For instance, the EU DC CoC utilises Power Utilisation Effectiveness (PUE) as a key metric to assess the overall efficiency of a data centre. PUE represents the ratio of total data centre input power to IT load power. The lower the PUE value, the higher the efficiency of the facility. The ultimate goal according to Best practices is to achieve a PUE close to 1.0, indicating a perfectly efficient data centre where almost all power is delivered to IT equipment.

This document is reviewed periodically by industrial professionals as well as independent experts, and updated, providing the most recent technological advances to be incorporated. Some of these best practices are mandatory, while others are optional. However, the Assessment Framework supplements the Best Practises document by making it more requirement-driven rather than recommendation oriented. This gives auditors the tools they need to determine if data centres are following the Practises appropriately, and it helps market participants to complete their Taxonomy alignment disclosures as part of their non-financial reporting without ambiguity.

Since its launch in 2008, more than 500 data centres have joined the EU DC CoC to improve their energy efficiency. Participants who demonstrate a significant reduction in their energy consumption are eligible for the annual EU Data Centres Code of Conduct Awards. In line with the EED, the Commission will adopt a delegated act to establish a common EU scheme for the reporting of the sustainability of data centres within EU.

According to Koronen and others the European Commission confronts multiple challenges in attempting to guide future data centre growth in a sustainable direction. The first difficulty is that the expansion of data centres and accompanying infrastructures in the digitalized economy is moving at an unprecedented rate, making projections difficult. As a result of a highly inventive sector, the adoption of regulatory policies will be delayed in comparison to technological and commercial progress [24]. The second challenge is the division of competences between member states and the EU, where the member states have a significant influence over how different energy policies are implemented.

6. Water efficiency policies in the EU

For the last 10 years, data centre operators have been scrutinised for the massive quantities of electrical power they require to store digital data. The quantity of water many institutions require to maintain cooling is coming to the fore as a result of climate change and rising worries about the water problem. According to Hintemann, there is often a conflict of interest: if a data center uses more water, it needs less energy, and if it uses more energy, it needs less water [25].

Water too is becoming a scarce resource – 2022's hottest summer on record saw major European waterways reaching a historic low point. According to European Commission experts, 2022 drought was the worst in 500 years. Even in nations that were previously thought to have a sufficient water supply, the water deficit has generated concern.

With pressure increasing on both resources and on design conditions, operators have to deal with a host of pressure points all appearing at the same time. Data centres need water to cool servers, which can have a negative influence on the availability of local water sources. According to Graphical Research, the overall European data centre cooling market (air and liquid cooling) was valued at 3.5 billion USD in 2020 and is expected to expand at a 15% growth rate between 2021 and 2027 [26]. According to the same report, the Europe data centre liquid cooling market will reach 650 USD million in 2021 and grow at a 20% CAGR from 2022 to 2028 [26]. Based on these numbers, it is estimated that liquid cooling accounts for around 20% of the entire cooling market in Europe. [27] Given its existing benefits over air-cooled systems, the market revenue for liquid cooling systems is expected to expand rapidly until 2027.

In 2022, the Climate Neutral Data Centre Pact (CNDCP), a self-regulatory initiative signed by 74 data centre operators and 23 associations, presented its proposed metrics for water conservation to the European Commission [28]. The CNDCP has suggested to the European Commission a target of 400 ml per kWh (400 litres per MWh) of computer power by 2040. This voluntary aim is quite ambitious and illustrates the European data centre industry's commitment to lowering its environmental effect.

Alternative cooling technologies (such as air cooling or evaporative cooling), which use significantly less water than typical water-based cooling systems but consume a lot of energy (comparatively), are best practises for lowering water usage in data centres [27]. Furthermore, data centres can increase efficiency by implementing closed-loop cooling systems, in which the same water is recirculated within the cooling system and does not need to be replenished from an external source, recycling and reusing wastewater, virtualizing servers, using energy-efficient hardware, and routinely maintaining cooling systems [27].

Google revealed in March 2023 that it is working on new cooling methods that might drastically reduce the amount of water used in its data centre operations [28]. It has not published the specifics of this new technology; nonetheless, it has stated that it intends to decrease its water use in half. While this would not be enough to fulfil the CNDCP objective, it would be a significant accomplishment and the first of its sort in terms of improving water-usage efficiency.

Water usage is also included in EED. While there is no immediate legal obligation to reduce water use to an "efficient" level, reporting requirements do apply. The EED requires companies with certain power consumption levels to implement an energy management system that continuously audits their energy use and identifies measures for improvement or requires them to have an environmental management system in place. While the energy management system (which is different from an environmental management system) does not address efficiency of water usage, data centers are required to report their water usage under the Annex VII of the EED [22]. The Directive requires data center operators in particular to report on their total water consumption in cubic meters. Annex VII EED only speaks of "water usage" but requires the data to be based on the CEN/CENELEC EN standard 50600-4 (until a more specific Delegated Act is adopted by the EU Commission) [22].

These EED reporting obligations are the most specific ones, but there are several other requirements with their own focus and field of application. Some of the most notable are obligations under the Corporate Sustainability Reporting Directive (CSRD) [29] and the EU Taxonomy Regulation. Companies that fall under the CSRD (starting in 2025 with large "Public Interest Entities," but extending to listed SMEs in 2026) will need to report on their impacts on people and the external environment alongside the reporting of financial risks and opportunities impacted by environmental and social issues that they are facing. For each main risk, European Sustainability Reporting Standards (ESRS) apply. For water and marine resources, ESRS E3 requires, for example: a) how the enterprise affects water and marine resources; b) any actions taken to prevent or mitigate material or potential negative impact; c) actions to reduce water consumption (total water consumption in m3, total water consumption in areas of material water risk (local droughts), additional info regarding the local basin's water quality and quantity (we presume local municipalities will have this information), total water recycled and reused in m3, total water stored); d) plans and capacity of the enterprise to adapt its strategy and business model in line with the preservation and restoration of water and marine resources globally; e) the enterprise's material risks and opportunities from impact and dependencies on water and marine resources; f) the enterprise's sustainability policies related to water and marine resources [10]. The information must be published as part of the company's non-financial report and primarily targets investors, who can then make sustainability-driven investment decisions. To become effective on companies, EU member states must transpose the CSRD into national law.

Similar to the CSRD reporting obligations are the requirements of the EU Taxonomy Regulation [21], though the reporting standards are different. Companies that are obligated to publish non-financial reports also must include a section where they explain which business activities are taxonomy-eligible (which are defined in Delegated Acts and, by definition, mean that the activity has potential to be sustainable) as well as which activities are taxonomy-aligned. In different Delegated Acts, the European Commission has defined the requirements for taxonomy alignment of different activities in respect of each environmental goal. Data centers fall under activity no. 8.1 of the Climate Delegated Act. [30] For instance, to be taxonomy aligned, data centers must demonstrate "best efforts" to implement all expected practices of the European Code of Conduct on Data Centre Energy Efficiency. Some of these expected practices have an indirect impact on water usage, for instance (e.g. optimizing cooling-system operating temperatures), though some practices that have a more obvious impact on water usage are only optional (e.g. capturing rain water).

7. The regulation on electricity uses and cooling system of data center in China.

In China, the National Development and Reform Commission mention that one of the main goals is to foster the green and high-quality development of "new infrastructure", a term that refers to digital-age assets like data centers and 5G networks. The action plan, released by the NDRC and three other central government departments is in accordance with the country's efforts to peak carbon dioxide emissions by 2030, achieve carbon neutrality by 2060 and promote low-carbon and sustainable growth. Under the plan, 5G networks should figure in the plans for construction of transportation, energy, industry and municipal infrastructure, and efforts should be made to optimize the layout of data centers.

The central and provincial governments released several rules, guidelines, opinions about regulation on data construction and energy efficiency. The policies to solve problems by high electricity and water consumption have two dimensions: control of construction data and energy and water efficiency. Besides legal rules, governments also provide technical standards to specify energy thrift regulation. The feature of China's regulation on data center is that the central government offers general rules, but provincial government make specific rules according to their own circumstances. This makes the legal environment in different provinces nonuniform.

7.1. Laws and policies at the national level.

According to GWLETC's report, a number of policies have been introduced at the national level to promote the green and low-carbon development of data centers.[17] Combining GWLETC's report and CAICT's White Paper, the information of relevant documents is summarized below:

Table 1. Chinese data center policies at the national level (Selected).

Release Time	Department	Title
2017	MIIT	Guiding Opinions on the Construction and Location of Data Centers. Guidelines for the Development of National Data Center Applications (2017)
January 2019	MIIT, State Organ Affairs Administration, National Energy Administration	Guiding Opinion on strengthening the construction of green data centers. (The 2019 Opinion)
October 2021	National Development and Reform Commission (NDRC), MIIT, and other five departments	Opinions on the Strict Energy Efficiency Constraints to Promote Energy Conservation and Carbon Reduction in Key Areas. (The Opinion 2021)
November 2021	NDRC, the Administration of	Implementation Plan for Carbon Peak

	State Council Organs and other departments	Achievement by Carrying Out Green and Low Carbon Leadership Actions in Public Institutions. (The Implementation Plan of Public Institutions)
December 2021	NDRC, National Energy Administration	Implementation Plan for Promoting Green and High-Quality Development of Data Centers and New Infrastructure, including 5G, by Implementing the Requirements of the Peak Carbon and Carbon Neutral Targets (The Implementation Plan of Carbon Neutral Target)

Source: GWLETC's report and CAICT's White Paper

These policies in 2017 promote the transfer of data center construction to the western China where the climate is suitable, energy is sufficient, and land rental prices are lower, by dividing the types of data center construction regions and adopting differentiated policy measures [2]. After the implementation of the policy, data centers in the western provinces, represented by Inner Mongolia and Guizhou, have achieved rapid development, and the number and scale of construction have increased rapidly [2].

The 2019 Opinion aims that "the average energy consumption of data centers basically reaches the international advanced level; power utilization efficiency (PUE) of newly built large and super-large data centers are less than 1.4; old energy-consuming equipment is basically phased out; the efficiency of water resources uses, and clean energy applications are significantly increased" [31].

Reducing the basic energy consumption and improving energy efficiency has already become a target for data centres in China. To help to achieve the goal of "carbon emission peak and carbon neutrality" a number of Chinese bodies, such as The National Development and Reform Commission, National Energy Administration, Office of the Central Cyberspace Affairs Commission, and Ministry of Industry and Information Technology have jointly issued an implementation plan to promote green and high-quality development of new infrastructure for things like data centres and 5G in November 2021. This implementation plan requires forming a green and comprehensive integration operation pattern by 2025, with a significant improvement of electricity and renewable energy utilization efficiency of data centres. The goal of the 2021 plan on energy efficiency is that "by 2025, the data center PUE will generally not exceed 1.5" [32]. It furtherly specified the requirements for optimizing the overall energy efficiency of the data center [32]. The Implementation Plan of Public Institutions is to proposes that "all newly built large-scale and mega data centers have met the requirements for green data centers, with a green and low-carbon rating of 4A or above and a PUE of 1.3 or less" [33]. The Implementation Plan of Carbon Neutral Target added that PUE of national hub should be down to below 1.25 [34]. These targets are considered to help for achieving the goal of carbon peaking and carbon neutrality. According to the strategy, data centres in the Eastern and Western regions will achieve computational power balance, and the total utilisation rate of national data centres would undoubtedly grow. Furthermore, the utilisation rate of data centres in western portions would increase from 30% to more than 50%.

From Table 1, it can be found that that the policy at the central level aims to balance the promotion of data center construction and energy and water efficiency. The Chinese central government encourages to develop data centers in Western part of the country where relevant sources are cheaper. It also gives a gradual requirement on data center's PUE. The requirement increases each year according to the scale of data centers. China is very careful on solving the problems caused by the high consumption of energy and try to avoid negative effects on development of economy and technology. Besides, such divergent goals influence the rules and policies at regional level, which can be very different.

7.2. Diverse regulations in provincial regions.

In terms of local policies, different regions have adopted different policies and measures for data center construction due to the differences of local economic development and the layout of industrial structure and regional resource conditions [35]. Big cities, such as Beijing and Shanghai, strictly control the construction of data center, while provincial regions, such as Inner Mongolia, Guizhou and Ningxia, actively introduce and expand data center constructions. [35] According to the regulations summarized by Zhonglun Law firm and GWLETC's report, there are different relevant regional rules, which are provided bellow [36]:

Table 2. Chinese data center policies at the regional level (selected).

Region	Rules
Beijing	New construction and expansion of data centers in information processing and storage support services for Internet data services are prohibited (except for cloud computing data centers with a PUE value of 1.4 or less). Prohibition of new construction and expansion of data centers in information processing and storage support services in Internet data service. [37].
	Data centers of backup storage function should shut down: average annual PUE higher than 2.0 or an average stand-alone power of less than 2.5 kilowatts, or an average shelving rate of less than 30%; Data centers need to be transformed: average annual PUE higher than 1.8 or average single rack power lower than 3 kilowatts. PUE of computing cloud data centers should not be higher than 1.3, and the PUE of edge computing centers should not be higher than 1.6, and untransformed data centers will be gradually vacate. [38].
Shanghai	The comprehensive energy efficiency index (PUE) of newly-built data centers will not exceed 1.3; the layout of high-end and green data centers will be controlled at 60,000 new racks and 160,000 in total. Promote energy-saving technological reform and structural adjustment of data centers, with the PUE of stock renovation data centers not higher than 1.4, and the PUE of newly-built data centers limited to less than 1.. [39].
	The number of new racks in the city's Internet data centers is strictly controlled within 60,000 racks; the PUE value of newly built Internet data centers is strictly controlled below 1.3, and the PUE value of rebuilt Internet data centers is strictly controlled below 1.. [40].
	Strictly control the scale, layout and functions of Internet data centers in the city, and adhere to "limited, green, intensive and efficient" [41].

Jiangsu	Newly built (expanded) large-scale data centers and data centers above should meet the requirements of green data centers, with PUE lower than 1.3 and green low-carbon grade of 4A or above. The PUE of small and medium-sized data centers should be no higher than 1.5. [42].
Shenzhen	To follow up on the PUE, the new energy consumption is given different levels of support. For data centers with a PUE of 1.35-1.40 (including 1.35), the new energy consumption can be supported by 10% or less of the actual replacement; for a PUE of 1.30-1.35 (including 1.30), the new energy consumption can be supported by 20% or less of the actual replacement; for a PUE of 1.25-1.30 (including 1.25), the new energy consumption can be supported by 30% or less of the actual replacement; for a PUE below 1.25, the new energy consumption can be supported by 30% or less of the actual replacement; and the new energy consumption can be supported by different levels of the actual replacement. For a PUE value of 1.25-1.30 (inclusive), the new energy consumption can be supported by 30% or less of the actual substitution amount; and the new energy consumption can be supported by more than 40% of the actual substitution amount for a PUE value of less than 1.2. [43].
Zhejiang	Focused support will be given to newly built data centers with PUE below 1.5 to meet layout-oriented requirements, as well as to constructed data centers with PUE below 2.0 after consolidation, renovation and upgrading, and tariffs for large-scale industrial power consumption can be implemented if they meet the requirements of large-scale industrial power consumption conditions. It supports enterprises to use industrial abandoned plants and power supply and distribution facilities that can meet the requirements for data center construction to build new or renovate high-level data centers. The annual growth rate of data centers will be controlled at less than 30. [44].
Hangzhou, Zhejiang	By 2025, the number of city's large (mega) data centers will be around 10, and the total number of data center servers will reach about 1 million. The PUE value of newly built data centers will be no higher than 1.4, and the PUE value of renovated data centers will be no higher than 1.. [45].
Inner Mongolia	Focusing on green data centers and the like, the construction of data centers, network channels and basic platforms will be further strengthened. Special funds have been set up to support the upgrading of information network infrastructure and the construction of government network platforms and public service platform. [46].
	To build a green data center base with Helinger New District as the core and a reasonable layout in the east, middle and west, and to strive to make Inner Mongolia a big data center in northern China. Optimize the spatial layout of green data center construction. [47].

Source: Zhonglun Law Firm's a legal guide and GWLETC's report.

From the above table, it can be found that the policies in different parts of China are not uniform. The land, water, and electricity resources in big cities such as Beijing, Shanghai, and Shenzhen are relatively scarce, and the requirements for data center energy efficiency and carbon emissions are more stringen. [2]. Data centers with high PUE will be even vacated and closed, and new constructions are not permitted. In other provinces (or cities) in Southern and Eastern China, the PUE of data centers are required to be decreased. However, in places like Inner Mongolia, the construction of data center is encouraged even though "green" is still a requirement. The GWLETC's report stipulates that "Western China has satisfactory natural environments, sufficient land, energy, and other resources, but the local data center market demand is relatively low; the Eastern region has strong market demand, but the cost of land, power, personnel and other factors of production is higher" [2]. This unbalanced reality in different part of China makes that "synergistic development between the East and West is gradually becoming a trend [2]. Inner Mongolia, Guizhou and other places made preferential policies on electricity, land and tax, which effectively help reduce costs of construction and operation [2]. Therefore, energy efficiency and data center development are balanced by setting different policies in the country.

7.3. General Rules on Water efficiency.

China's water woes are well established and challenge socioeconomic development, especially as demand for fresh water is quickly increasing. Forecasts predict that by 2030, China's water demand will surpass 800 billion cubic meters, putting further pressure on the country's limited water supplies. Despite efforts to increase water availability, China still faces a water supply gap that some domestic scholars estimate could reach 25 % by 2030.

In China, there is no water efficiency rules specifically for data centers but only for general water efficiency. At the national level, the Ministry of Construction promulgated the "Rule of water efficiency in urban areas" in 1988 [48]. This rule is about the planned policy on water usage and water supply. Governments in urban areas are authorized to give sanctions and fines if any construction program does not respect the rule. Since this rule was promulgated so early, it does not contain any information about data center's water efficiency, a question which arises later with the development of IT technologies.

In 2016, China has amended the Water Law [49]. The law has a chapter to regulate the issue of water efficiency, and it encourages new technologies that can increase the water efficiency. Ministry of Water Resources also set policies to encourage citizens and enterprises to save water and increase water efficiency. It also made the draft of "Rule of water efficiency" in 2016, which is waiting for the authorization of the State Council. Rule of water efficiency was made to implement Water law from the perspective of efficiency. Water efficiency is defined as "optimizing the water use structure, establishing an economic development model and industrial structure adapted to the conditions of water resources, as well as adopting comprehensive economic, technological and administrative measures to reduce the consumption and loss of water resources and to make rational and efficient use of water resources" [50]. Article 4 of this rules claims that the government promote water efficiency in the industrial policies, claiming that high water consumption in the industry will be limited [50]. National rules are also applicable to data centers, but they are not the primary target for these objectives. Compared with other industries like steel, concrete, mining, and electricity generation, data center industry in China has very reduced water consumption.

In January 2022, China released a plan to improve the country's capability to safeguard its water security during the 14th Five-Year Plan period (2021-2025). The plan, jointly released by the National Development and Reform Commission and the Ministry of Water Resources, is the first five-year plan (FYP) for water security to be implemented nationally. With an overall aim of significantly strengthening China's national water security capability by 2025, this comprehensive water plan responds to China's significant national water challenges. This plan aims to significantly enhance China's national water security capability by addressing water concerns through four main goals: improving the ability to prevent floods and droughts; improving the ability to conserve water resources; improving water resources and optimizing allocation capacity; and strengthening the ecological protection and governance of large rivers and lakes.

China's water supply and quality are severely undermined by worsening interlinked factors of water scarcity, rapid urbanization, population growth, pollution, climate change impacts, and competing water demands. These concerns have been acknowledged by China's top officials, including President Xi Jinping. By addressing these critical areas of concern, the water security plan seeks to safeguard China's water resources at the national level and enter a new era of "water management with Chinese characteristics." This plan will prompt the government to draft new rules in China, related to water efficiency, giving also competencies to local government to promote their own local rules.

At the regional levels, there are several rules promulgated by provincial governments. For example, Shanxi, Jinlin, Hebei, Hubei, Jiangsu, Anhui, Heilongjiang, Gansu, Liaoning, Shandong provinces promulgated or drafted their own water efficiency rules. At the city level, Shenzhen, Wuhan, Dalian, and other cities also have their own rules. These provincial or city rules shall be in accordance with national rules: establishing regulations in a general way rather than in specific fields or industries. In July 2023, Beijing Development and Reform Commission issued a new rule on energy efficiency related to data centers. It encourages data centers to use water thrift systems with high efficiency. Meanwhile, data centers should use recycled water for cooling systems. From arrangements at the regional level, it can be found that Chinese rules still consider water efficiency for data center as a part of energy efficiency the whole industry.

8. Conclusions

Data centres have a lot of potential to help with decarbonization through digitalization, as well as to ensure that the global economy has access to new technologies to develop and expand sustainably. As Europe marches towards its 2030 energy goals, the role of data centers in achieving these targets is undeniable. With the new regulations in play, data center operators and developers across the EU will need to reevaluate, innovate, and adopt best practices to ensure compliance and contribute to a greener future.

China also have announced the target to have carbon dioxide emission peak before 2030 and become carbon neutral before 2060, the topic has been of widespread concern for all industries. With the continuous development of China's digital economy, data traffic is exploding and as a result, the data centre market has maintained rapid growth. Overall energy efficiency of data centres in China is still lagging behind the EU and even the international level, and the utilization rate of renewable energy remains low. However, China have already started to work on necessary policies to encourages the use of additional renewable energy such as wind and solar power, as well as the large-scale use of modular hydrogen cells and solar panel parks in tiny or peripheral data centres. Technically, the application range of new green and low-carbon technologies will gradually grow. Cloud computing and other technologies will pool and virtualize data centre resources to boost server utilisation while consuming the same amount of electricity. Using AI technology to optimise operation control is quickly becoming a significant technique to minimise data centre energy usage.

The EU Member States and Chinese governments actively promote policies that require technology companies to utilize innovative technologies to improve data centers' operational efficiency and cut power consumption. The governments in both jurisdictions ask data centers to increase computing efficiency, save computing energy consumption, and truly meet the needs of future smart computing. For this reason, it is important the collaboration of the EU and Chinese technology firms with the government to work on green solutions to reduce electricity and energy consumption of data centers, but also transnationally.

Data centre energy efficiency in both the EU and China is already increasing significantly, and it is critical to maintain this progress if data centre traffic and workloads continue to grow as predicted. Centralization and the replacement of small installations with cloud services are major drivers of total energy efficiency and also aid in the integration of energy systems. With the EU's and China climate and energy policy outlined up to 2030 and 2060 respectively with legally enforceable objectives, it is useful to evaluate the potential for demand response and energy system integration by estimating how much power data centres would require. Application of green technologies is an important measure for energy-saving and low-carbon development of data centers, so encouraging innovation and application of green technologies in data centre is also a priority task in relevant policies.

For the safe operation and energy-saving evaluation of data centers, it is very important to select appropriate energy efficiency evaluation indicators. Both jurisdictions, the EU and China, have as an aim to reduce, PUE, as a common indicator to measure the efficiency of energy utilization in data centers. Hence, PUE is an imprecise metric that varies based on other circumstances. Although PUE is not a perfect approach to assess overall datacenter sustainability, it is widely used in both jurisdictions in their industries as a starting point for thinking about efficiency and will be a vital measure to monitor as part of larger sustainability programmes and goals. Adjusting the datacenter to consume less power (and hence have a lower PUE) may necessitate the facility using more water or affecting other aspects of the environment.

However, water also became a scarce resource and both the EU and China, and the drought experienced in the last years prompted both countries to elaborate and promote water efficiency policies in the whole industry, not only for data centres. Water consumption is a dead angle in the calculation of data centers' energy efficiency. This industry has to date almost exclusively focused on PUE. Meanwhile, discussions about normalizing a "water usage effectiveness" indicator are still ongoing, at ISO level in both jurisdictions. To solve this problem a solution may be the reutilization of recycled water and the placement of data centers in a colder environment.

Thus, data centres may play an important part in decarbonizing EU and China's energy system by enabling the development of additional renewable energy on the electric grid, offering carbon-free grid services, and facilitating heat recovery and reuse where viable and practical. Furthermore, data centers can promote a shared digital and climate-neutral future by working in the most efficient and sustainable manner.

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