BIG DATA ON A DEAD PLANET: THE DIGITAL TRANSITION'S NEGLECTED ENVIRONMENTAL IMPACTS

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INTRODUCTION

Data centres are spaces where the necessary resources for processing an organisation's information are concentrated, working as hubs and warehouses for data collection, storage, and transmission. The main spaces in a data centre are: the IT room, the support area, which is composed of the power and cooling system, and offices (Sovacool, Monyei, and Upham 2022). The IT room consists of a room where the IT equipment in the form of racks full of servers is installed, see Fig. 1.These servers are where the data or information is stored. As all the equipment is electronic, data centres are powered with electricity and usually have backup systems.

Fig. 1 An IT room with racks full of servers. Imagen source: (FS community 2021)

Digitalisation and new digital technologies provoke a growing demand for data in most economic sectors (IEA 2017). Some digital services include the Internet of things, 5G, blockchain, crypto, artificial intelligence, machine learning and virtual reality. For instance, the rapid growth in video traffic over mobile networks is growing at 55% per year (IEA 2020), which is expected to increase with a multiplier effect on traffic as video qualities increase (CISCO 2020). Thus, worldwide data could reach 175 ZB in 2025 from 33 ZB in 2018 (Fenn and Fesch 2020). These predictions usually become outdated with higher demands, as shown in the most recent prediction that expects 181 ZB by 2025 (Statista Research Department 2022), Fig. 2. This trend will be further reinforced in the EU with the «digital transition» strategy (European Commission 2022b).

It is important to highlight that 55% of data produced by organisations is used only once (Jackson and Hodgkinson 2022), meaning that a large amount of stored data is useless.

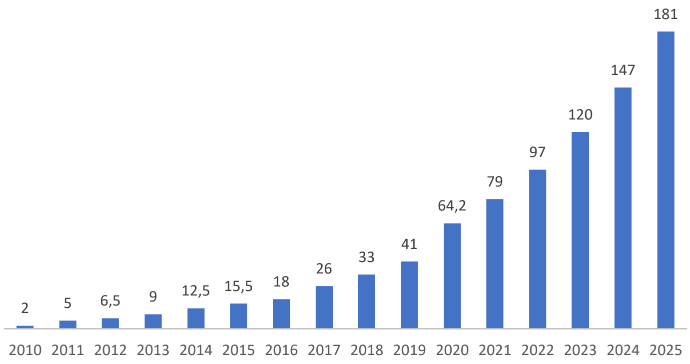

Fig. 2 Volume of data created in the world in Zettabytes. Data obtained in: (Statista Research Department 2022)

As these computing requirements have exploded in recent years, the demand for data centres, network traffic and workloads have multiplied. Despite this strong growth, the electricity consumption of data centres has increased at a lower rate (Masanet et al. 2020). Fig. 3 left shows the increase in internet traffic, volume of data, data centres workloads and internet users compared to the energy demand of data centres. Internet traffic has more than quintupled since 2015, workloads have tripled, and data centre energy use has increased by 40%. This is thanks to increasingly efficient IT hardware and a shift to hyper-scale data centres (Masanet et al. 2020). Fig. 3 (right) shows the increase in energy demand[1] for data centres, data transmission networks and crypto mining since 2015. Data centres' electricity consumption in 2021 was 220-320 TWh, around 1% of global electricity. Energy for cryptocurrency mining was 100-140 TWh in 2021 and 60-70 TWh in 2020 (IEA 2022b), increasing by 30 times since 2015. Data transmission network electricity consumption was 260-340 TWh during 2021 (IEA 2022b). Together, they account for 2.9% of global electricity consumption and 0.9% of global CO2 emissions from energy combustion and industrial processes[2] in 2021.

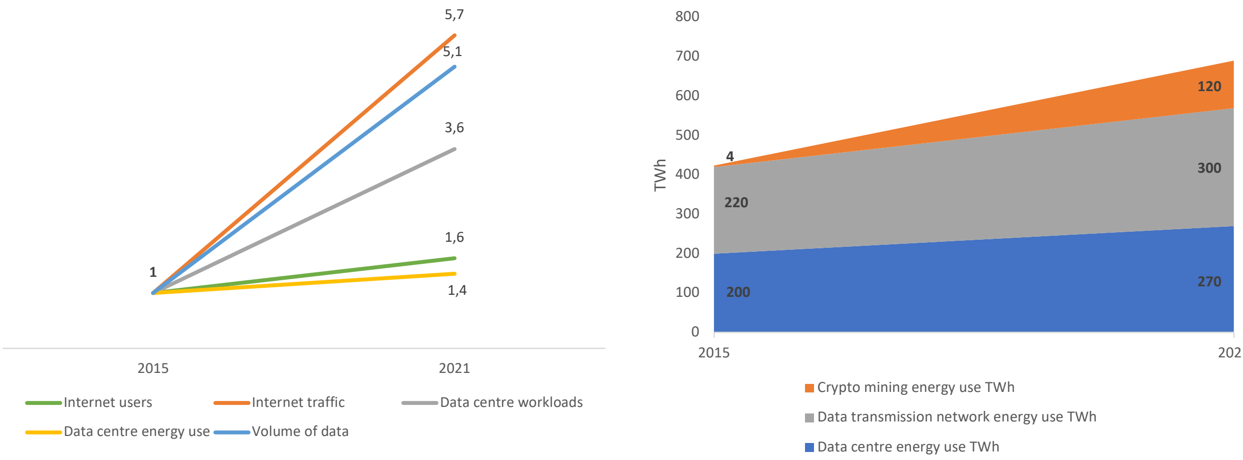

Fig. 3 Left: Multiplying factor in internet traffic, data centre workloads, volume of data and energy use since 2015. Right: Global data centre, data transmission networks and crypto mining energy demand. Data obtained in: (IEA 2022b) and (Statista Research Department 2022)

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[1] Although there is no conformity in the literature about the total energy demand in data centres, we show the most recent IEA results (IEA 2022b).

[2] It has been estimated considering the world average emissions associated to electricity production 475 gCO2eq/kWh and the emissions from global energy combustion and industrial processes 36.3 Gt CO2 (IEA 2022a). If Global greenhouse gas emissions in 2019 are considered: 49.76 Gt CO2e (measured in CO2 equivalent), emissions from data centres, cryptomining and networks represent 0.66% of global GHG emissions (Ritchie and Roser 2022).

In Europe, the electricity demand has continuously increased recently, see Fig. 4. The Joint Research Centre (JRC) estimated that electricity demand by 2020 for data centres was 104 TWh (3.7% of the European electricity demand), expected to increase to 160 TWh by 2030 (Dodd et al. 2020). This may complicate EU plans for the energy transition, which has recently been shifted in reaction to Russia's invasion of Ukraine and the subsequent decisions to move away from Russian energy sources as well as decrease demand.

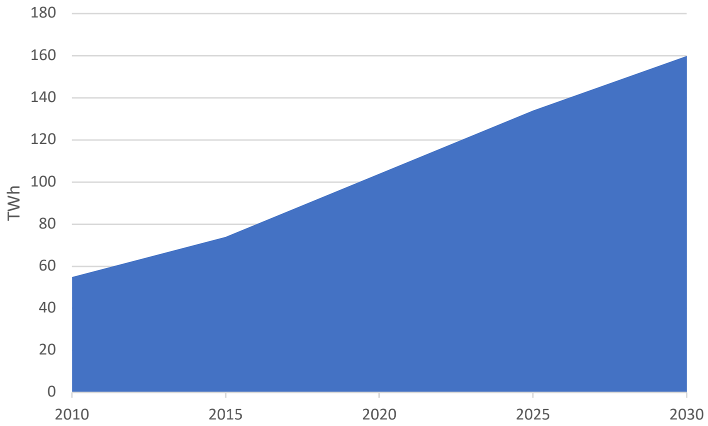

Fig. 4 Data centre energy consumption in Europe. Data obtained from (Dodd et al. 2020)

The complexity of digital services' direct and indirect effects makes it immensely challenging to quantify the net environmental impacts of data centres and digitalisation. The alternative forms of consumption as accessing streaming media, are leading to a significant rebound effect in electricity demand and computing requirements (IEA 2020). In addition, other impacts, such as water consumption and the use of materials, are also becoming the subject of public debate. Thus, this study is focused on the direct and indirect impacts of data centres.

In section 2, we consider the impacts of data centres. We divide them between environmental water, energy, raw materials, and social impacts. In section 3, we make a small summary of current policies related to data centres. Section 4 presents the cases of Ireland, Netherlands and Sweden and their legal and political frameworks as specific examples in the EU. In section 5, we present policy considerations to decrease the impact of data centres considering the current policies, the impacts of section 2, and the case studies. Finally, section 6 concludes with the most important aspects to consider.

2

IMPACTS

Data centre impacts are usually divided into three stages: production or manufacturing, operation, and end of life. Production refers to the steps as procuring materials, integrated circuits building, data centre construction, packaging and assembly. Operation refers to the utilisation, hardware lifetime and energy consumption. End of life refers to the disposal of materials. We present the impacts of data centres as far as data has been available. Data gathering has been one of the most challenging tasks due to the lack of transparency.

2.1 ENVIRONMENTAL IMPACTS

Life cycle assessment (LCA) is a methodology that considers all the processes from the cradle to the grave. When this methodology is applied to data centres, the highest environmental impact is obtained in the operation category (80%), production or manufacturing accounts for (19.78%) and the end of life has a minimal impact (Whitehead, Andrews, and Shah 2015). This is due to the use of fossil fuels as an electrical energy source and the disposal of metal refining waste products during the manufacture of IT components and electricity distribution networks, which have an impact as a carcinogenic effect (Flucker, Tozer, and Whitehead 2018).

In terms of carbon emissions[3], a comparison depending on the electricity source during a server life cycle of 3 years is shown in Fig. 5., considering: Sweden which represents a low carbon emissions thanks to renewable energy and nuclear power (8 gCO2/kWh), Ireland (281 gCO2/kWh) and Netherlands (333 gCO2/kWh) (EEA 2021) [4], the world average (475 gCO2/kWh (IEA 2019)) and using only fossil fuels sources (490 gCO2/kWh for natural gas and 820 gCO2/kWh for coal). The server operation has been compared with the server manufacturing. The manufacturing of a Dell rack server accounts for 471 kg CO2 eq (M. Stutz, O'Connell, and Pflueger 2012).

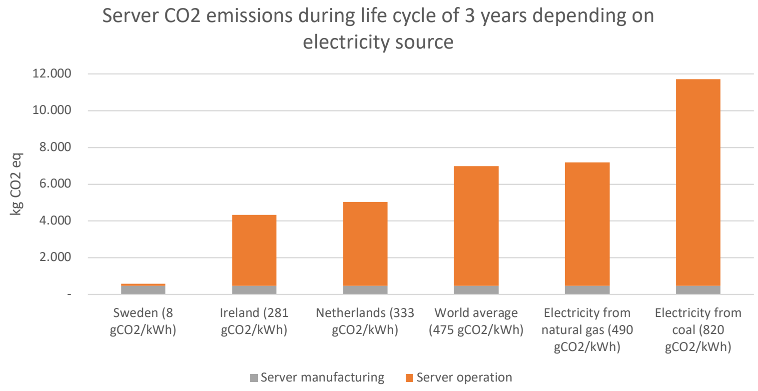

Fig. 5 Emissions of a Dell server depending on the electricity source during a life cycle of 3 years

If low carbon emission sources do not supply electricity, the most significant pollution impact is energy consumption during operation. Thus, efforts should be concentrated on transforming energy sources into renewable sources and reducing the electricity demand for IT equipment. Recently, data

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[3] In order to make a comparison between the electricity systems, calculations have been made on the basis of carbon emissions. Other environmental impacts due to radiation or the use of waste for electricity generation have not been considered, but this does not mean that their impacts are not important.

[4] Life cycle emissions from renewables are not included, as some other data sources show Sweden's emissions at 29 gCO2/kWh, Ireland's emissions at 313 gCO2/kWh and Netherland's emissions at 516 gCO2/kWh in 2021 (Nowtricity 2022).

centres are starting to purchase renewable energy to supply their electricity demands through power purchase agreements - PPAs. This approach is not without controversy, as it does not imply physically consuming renewable energy from the network, serving more as a balance in the company's accounts (Schulze 2022).

The operation category impact is much lower if electricity is supplied by zero-carbon emission sources particularly renewable energy. Using Sweden as an example of low carbon energy sources, the embodied impact is the most critical factor due to the manufacturing of IT products, which represents 77% of emissions during its 3 years life cycle (refreshing server period of 3 years). Server operation and post-use would account for 22% and 1%, respectively (Fenn and Fesch 2020). See Fig. 6 left. If life cycle emissions during manufacturing of renewable power plants were counted (Nowtricity 2022), see Fig. 6 right, server CO2 emissions during operation would be higher but still lower than manufacturing emissions, representing 54% of emissions.

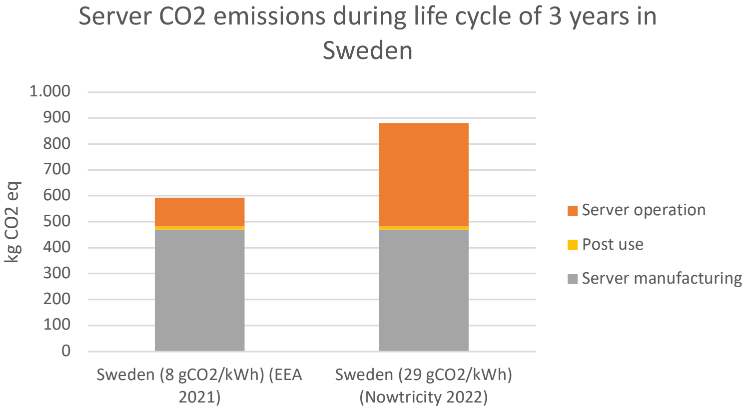

Fig. 6 Emissions of a Dell server in Sweden during a life cycle of 3 years

Assuming that electricity is supplied by renewable energy through PPAs, recent studies show that scope[5] 3 is becoming the most intensive carbon emission for companies such as Facebook and Google, see Fig. 7 (Gupta et al. 2021). Even more, if the change in Hardware (HW) footprint disclosure practice is considered. Furthermore, only 12% of respondents in a recent survey collected carbon emissions data of scope 1, 2 and 3 in their data centres (Davis et al. 2022). This highlights the importance of improving carbon accounting and reporting.

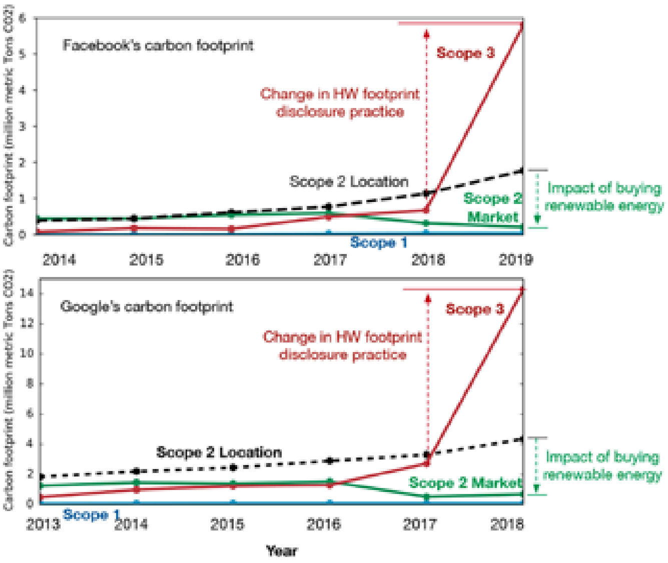

Fig. 7 Carbon footprint of Facebook and Google.
Source: (Gupta et al. 2021)

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[5] Scope 1 (blue) emissions come from facility use of refrigerants, natural gas, and diesel. Scope 2 (green) emissions come from purchased electricity. Scope 3 (red) emissions come from the supply chain, including employee travel, construction, and hardware manufacturing (Gupta et al. 2021).

Emissions from manufacturers such as Intel, AMD and TSMC using renewable energy may significantly reduce the environmental impact of hardware production. However, there would still be a significant impact from raw material extraction and manufacturing, such as bulk gas, wafers, PFCs and diffuse emissions, and the use of chemicals and gases (Gupta et al. 2021).

The life cycle analysis highlights the importance of transitioning to renewable energy sources and improving energy efficiency to reduce energy consumption, extending the server refreshing period, and changing to renewable energy sources in the manufacturing stage.

2.2 WATER

Water is usually used to cool the data centres as the IT equipment generates heat that needs to be evacuated to preserve the equipment. Many large data centre operators have stepped up their efforts to conserve water during the past decade, but progress across the industry has been slow. Some of the largest data centre owners have only recently begun collecting comprehensive water usage data across their portfolios; others are still working on it. Only 39% of respondents to a recent survey said their organisation collected water usage data (Davis et al. 2022), the other 61% did not collect data mainly because there is no business justification, which highlights the work that remains to be done.

Some traditional chilled water-cooling systems employ cooling towers for heat rejection, which consume and discharge large volumes of water but use less energy than air-cooled chillers. Evaporative cooling is used in modern low-energy data centres as this significantly reduces electricity consumption, albeit with increased water consumption, compared with air-cooled chillers. Thus, water scarcity threatens future growth and operational reliability even more with the recent droughts in the summer of 2022 (Judge 2022). Furthermore, discharged water has a high environmental impact as it requires its processing to decontaminate it before it is returned to its natural course. This impact is not evaluated typically in the LCA due to limited data and lack of focus on it (Shah, Chen, and Bash 2012).

In response to concerns about water consumption in data centres, The Green Grid developed the Water Usage Effectiveness metric (WUE). This metric considers the amount of water used per kWh of energy consumed. The WUE is measured in l/kWh. The world water consumption in data centres is between 20,188 and 32,806 m3 per MW, which means an average WUE of 1.8 litres per kWh (Shehabi et al. 2016).

The current trend among new data centres is to avoid water use for cooling using other techniques such as air cooling or other types of liquids (Vermeulen and Madsen 2021). Modern data centres have a much lower average use of water, such as 0.1 l/kWh (Open Compute Project 2022), 0.27 l/kWh as big tech Facebook reports (Facebook 2020), or even 0 l/kWh (Open Compute Project 2022), as shown in Fig. 8.

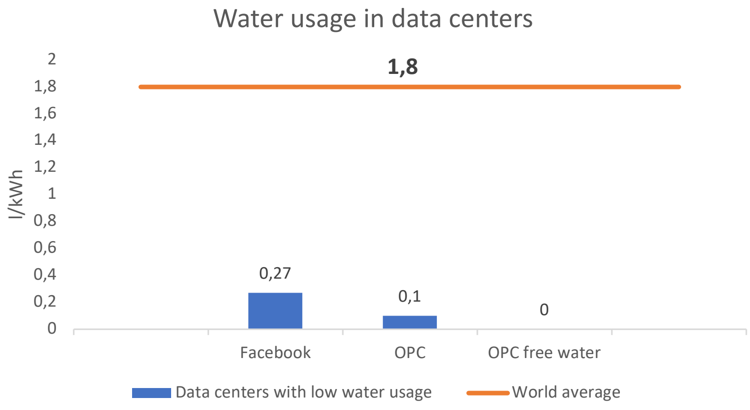

Fig. 8 Water usage in data centres world average vs low water usage data centres

2.3 ENERGY

Primary efforts are directed towards decreasing the energy demand of IT rooms, which is where data centres most intensively consume electricity. IT rooms represents 63% of the data centre energy demand, while the cooling system represents the remaining 37%. There are also opportunities to recover the waste heat from the cooling system, increasing the overall efficiency of a data centre.

2.3.1 Energy savings for IT

There are techniques which use power management to decrease energy demand. These techniques are Hardware-based Dynamic power management for computational clusters and grids, dynamic capacity planning for clusters, cloud migration and Virtual Machines (VM), which, thanks to server consolidation, allow several VMs to be run on a single host (Zakarya 2018). These energy savings have allowed for the creation of the laws of Moore and Koomey. Moore's Law states that the processing power (number of transistors in a dense integrated circuit) doubles about every two years, and Koomey's Law states that the energy efficiency of computing devices doubles every 1.5 years (Koomey et al. 2011). Moore's Law has been reported to decline since 2000 needing more time to double processing power (Jones 2018), which may comprise further energy efficiencies expected in the sector. It also implies higher costs, bigger and slower servers and more servers for the same load than expected.

However, increased computational needs due to new network traffic and new workloads have surpassed energy efficiency in the sector with a moderate global energy increase (Bol, Pirson, and Dekimpe 2021), (IEA 2022b) and a global carbon footprint increase, see Fig. 3. Establishing future projections is highly complex due to the tremendous technological uncertainty in digital environments, but some expected developments deserve to be considered. Considering uncertainties of the decline of Moore's law, the increase of data demand due to new technologies and both uncertainties combined, an increase in electricity demand is expected for all scenarios in 2030 according to a study performed by Koot and Wijnhoven (Koot and Wijnhoven 2021), see Fig. 9.

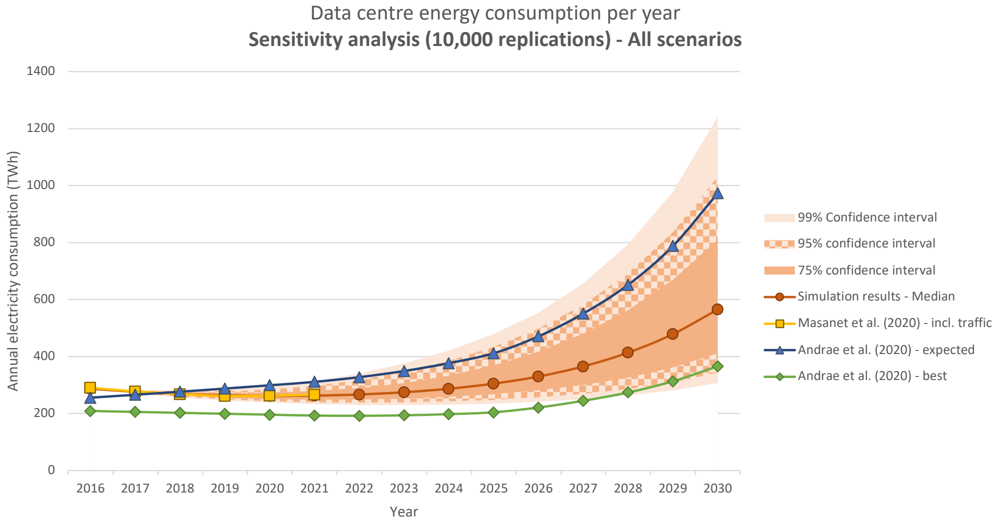

Fig. 9 Data centre energy consumption per year. Source: (Koot and Wijnhoven 2021)

For this reason, some studies call for sobriety in ICT usage and innovation combined with strong energy efficiency measures to tackle environmental challenges, because current innovations have increased growth instead of reducing consumption[6] (Bol, Pirson, and Dekimpe 2021).

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[6] Despite huge energy efficiency improvements over the last decades, global ICT energy and carbon footprints are still on the rise. Efficiency improvement thus cannot be the only ecological target as it is used to generate economic profit rather than used for global footprint reductions. This is reinforced in the context of growth policies, which amplify rebound effects (Bol, Pirson, and Dekimpe 2021).

2.3.2 Energy savings for cooling

Energy used for cooling may increase when the design is not suitable, for example, inadequate localisation of cooling, packed server rack layouts, poor airflow management, and a significant mechanical component. Energy efficiency is usually measured with the Power Usage Effectiveness (PUE), which compares the total facility power with the IT equipment power. A PUE value of 1 is ideal. The average value in the data centres globally is 1.5-1.59. However, Nordic countries have reached PUE between 1.05 and 1.3 (Sovacool, Monyei, and Upham 2022) thanks to their geographical location and ambient temperatures. New data centres have shown low PUE values too (Open Compute Project 2022).

There are several types of energy-saving cooling technologies for data centres:

- Free cooling with airside or water-side cooling, which depends strongly on location and serves for the low power density of data centres, is the most mature technology and usually has a PUE of 1.5-1.6.

- Liquid cooling with a cold plate or immersion liquid cooling allows for a high-power density and lower values of PUE, such as 1.03 (Zhang et al. 2022). It is a promising technology but must be used cautiously due to the danger of leaks (Sovacool, Monyei, and Upham 2022).

- Two-phase cooling with a heat pipe or thermosiphon can be combined with natural cooling sources to improve system efficiency.

- Thermal Energy Storage cooling mitigates the mismatch between energy supply and demand saving peaks in case of energy integration.

The global survey performed by Uptime Institute, Fig. 10, shows the average world PUE for a data centre since 2007. In Europe, the PUE is 1.46, slightly lower than the global average.

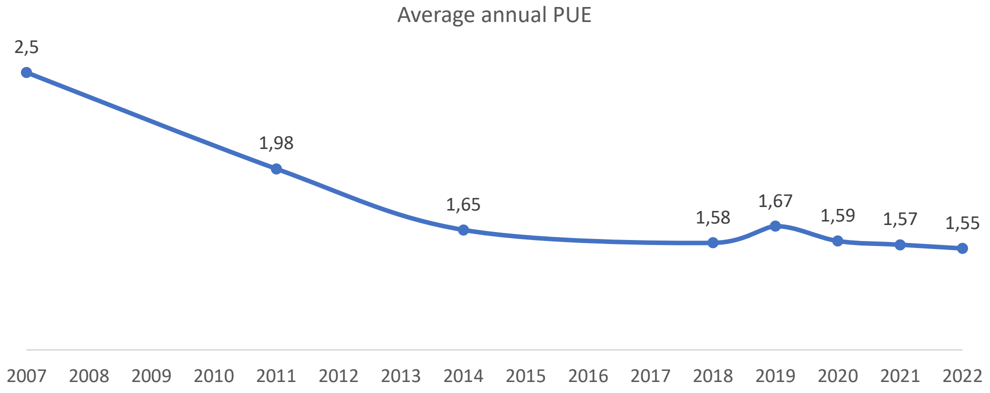

Fig. 10 PUE of world data centres. Data obtained in (Davis et al. 2022)

Fig. 10 shows that improvements in PUE have been marginal since 2013. Most new data centre PUE falls between 1.2 and 1.4, with examples of very efficient data centres falling to a PUE of 1.07 (Open Compute Project 2022), see Fig. 11. Yet thousands of older data centres still cannot be economically or safely upgraded, especially if high availability is required.

PUE values are based on the average PUE per site, regardless of size or age. Newer data centres, usually built by hyper-scale or colocation companies[7], tend to be much more efficient thanks to scale economy. Larger data centres show a lower PUE but with the same trend to stagnate (Ascierto and Lawrence 2020), which explains the continuous search for locations that allow a lower PUE, such as in Nordic countries.

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[7] Colocation services allow to store the servers of different users concentrated in the same data centre by renting space, thus making the data centres larger by grouping different users together. Hyperscale data centres are larger data centres that meet the technical, operational and pricing requirements of data-intensive companies and are usually exclusive to one company.

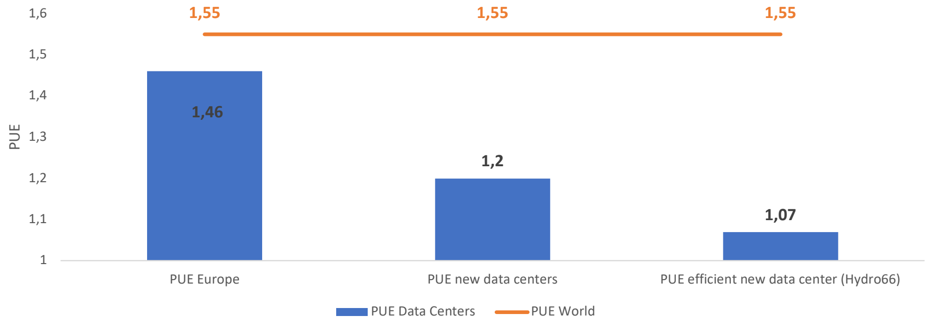

Fig. 11 PUE comparison between world, Europe, new and highly efficient data centres

In recent years the environmental operating range for air entering IT equipment has widened, working with hardware manufacturers to reduce the energy requirements of data centre cooling systems (Flucker, Tozer, and Whitehead 2018). Nevertheless, new IT equipment is more compact, increasing rack densities, which also increases the heat generation in data centres. It forces more IT cooling systems to be explicitly designed for liquid or two-phase cooling (Ascierto and Lawrence 2020).

2.3.3 Rack densities

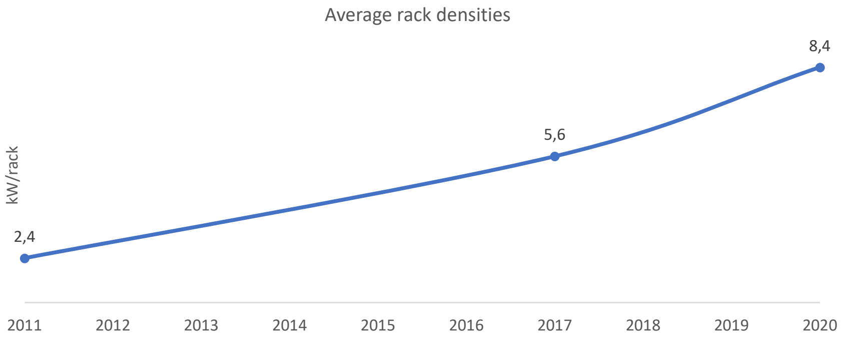

Fig. 12 Average density rack. Data obtained in (Ascierto and Lawrence 2020)

The power density per rack (kilowatts [kW] per cabinet) is a critical number in data centre design for cooling. There have been industry warnings about a meteoric rise in IT equipment rack power density for the past decade, reaching an average value of 8.4 kW/rack (Ascierto and Lawrence 2020), see Fig. 12.

One reason for this rise is the proliferation of compute-intensive workloads (AI, IoT, cryptocurrencies, and virtual reality), which drive the need for high-density racks. A recent survey shows that despite the most common rack power being 6 kW, the bigger the data centre facility, the higher the rack densities (Davis et al. 2022), but also shows that these facilities have a lower PUE. Furthermore, Fig. 13 shows the current trend shift toward hyperscale data centres, which typically use higher rack densities; this means that higher rack densities are expected in the future. On the other hand, the recent surge of smart solutions and 5G will require edge computing with edge data centres which are smaller and closer to the source (PwC 2019).

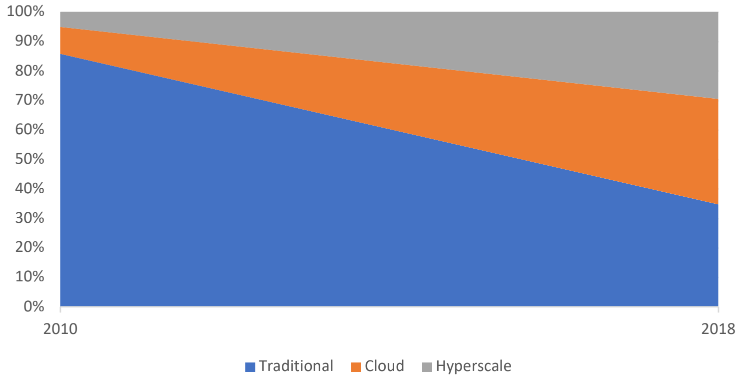

Fig. 13 Data centre type 2010-2018. Data obtained in (Masanet et al. 2020)

Rack densities of 20 kW and higher have become a reality for 25% of data centres (Davis et al. 2022). When rack densities are higher than 20-25 kW, direct liquid and precision air cooling become more economical and efficient, thus offering a possibility for the energy integration of data centres (Ascierto and Lawrence 2020).

2.3.4 Energy Integration

Energy integration is an opportunity as rack densities increase (Ascierto and Lawrence 2020), becoming more compact with a greater need for cooling. As a best-case scenario, each MWh of energy integration may save 260 kg CO2 eq using a conventional gas boiler (Dodd et al. 2020).

Examples of using waste heat in an industry nearby include drying biomass, pre-heating a power plant, or heat reuse through an Organic Rankine Cycle (Sovacool, Monyei, and Upham 2022) or even heating greenhouses and aquaculture. Nevertheless, they are examples limited to the existence of these industries nearby and their possible uses. Waste heat may be used too for district heating or refrigeration through absorption. Outlet temperatures from data centres are between 25°C to 35°C. Thus, for energy integration in the district heating system, the temperature must be raised to reach 75°C to 90 °C. However, fourth-generation district heating can be run at lower temperatures, such as 35°C-55°C (Koronen, Åhman, and Nilsson 2020).

There are some success stories with energy integration in data centres:

- DigiPlex Oslo Ulven accounted for a successful energy integration with district heating as it was built in the city centre. DigiPlex Oslo Rosenholm uses waste heat during winter as it has a campus nearby (Sovacool, Monyei, and Upham 2022).
- In Amsterdam Science Park, 1,300 apartments are now being heated. In Eindhoven, some 40 office buildings on the High Tech Campus and another data centre heat a swimming pool, school and nursery in Aalsmeer. Soon about 2,500 homes will be added in Groningen.

Nevertheless, practical experience shows that there are currently very few data centres in the EU with heat reuse, maybe less than 100 (Dodd et al. 2020). In a survey made to data centre owners, residual heat reuse was a dilemma. They stated that it was difficult to fulfil all the required conditions (a facility that demands heat, infrastructure to exchange the heat, a power plant or high voltage transmission lines to power de data centre). "Usually, if you are close to a power plant, you are too far away from a city or a facility that demands the heat. Or, if you build the data centre in a city, you have a longer transmission line, high costs, and transmission losses of 10–12% on power" (Sovacool, Monyei, and Upham 2022).

2.4 RAW MATERIALS

The manufacture of IT equipment is also resource intensive. Given the copious quantities of metals required and the complexity of manufacture, it also increases the demand for materials expected for the energy transition aggravating potential supply risks (Valero et al. 2018).

Refreshing servers are the primary raw material consumers during the life cycle. A survey data suggests that a slight majority of data centre managers think that the case for more frequent hardware refreshes has diminished; some reasons are the slowing down of Moore's Law (Ascierto and Lawrence 2020) and the semiconductor shortages (Davis et al. 2022). On the other hand, planned obsolescence in servers has been noted, either due to hardware failures or software renewal that is incompatible with old hardware, which forces servers to be refreshed. Fig. 14 shows the current trend in which data centres are starting to extend the refreshing time of servers.

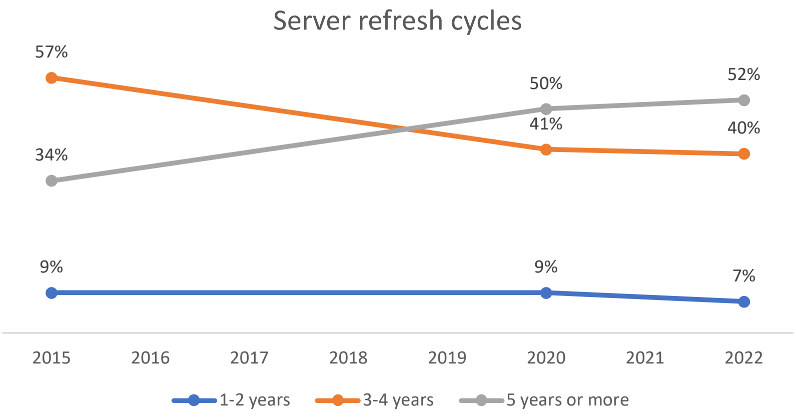

Fig. 14 Server refresh cycles in data centres. Data obtained from (Davis et al. 2022)

The typical composition of a 4.22 kW rack server is shown in Table 1 elaborated with data obtained in (Pehlken et al. 2020). This rack is made up of 13 servers. A data centre facility with a power of 4.22 MW is made up of these 1000 racks. A simple rack contains materials such as Antimony Sb, Barium Ba, Rare earth metals, Beryllium Be, Silicon Si, Indium In, Tantalum Ta, Bauxite, Niobium Nb and Gallium Ga. These materials are considered critical raw materials by the European Commission (European Commission 2020d) and have a low recycling rate (Graedel et al. 2011).

In an independent survey performed with data centres in Spain, it was noticed that new cables are usually installed when servers become obsolete. Obsolete cables are left uncollected, leading to a substantial accumulation of copper.

Table 1 Mineral composition in grams for a 4.22 kW rack

Material	Total (g)	End of Life Recycling Rate (%) (Graedel, Reck, and Miatto 2022)
Au	0.33	90%
Ag	1.50	35%
Pd	0.04	60%
Al	1,040.84	60%
Cu	897.04	48%
Fe	10,482.24	78%
Dy	0.08	0%
Nd	0.07	1%
Y	0.05	1%
Ba	13.02	0%
Ga	0.57	5%
In	2.09	5%
Nb	0.22	6%
Sb	3.59	5%
Ta	0.43	20%
Ti	2.37	70%
W	0.94	25%
Si	700.41	63%
Sn	2.31	30%
Be	0.00	21%

The demand for raw materials is aggravated because, in many cases, equipment is overdesigned for several reasons: due to a high Tier[8] level, clients that may build in some spare capacity when specifying their requirements, higher cost of outages (Davis et al. 2022), and designs using their safety margins. Data can be stored two and three times, requiring more servers. Plant sizing often results in a model selection which is the next size up (Flucker, Tozer, and Whitehead 2018). Designing for worst-case scenarios also implies that most mechanical components are oversized as a safety measure or duplicated. However, it may not be needed for all the IT services (Flucker, Tozer, and Whitehead 2018), as some examples of data centres work with a lower redundancy level (Sovacool, Monyei, and Upham 2022).

During the manufacturing and disposal of IT equipment, dangerous chemicals for the environment and health (such as mercury, lead, cadmium, chromium, polybrominated diphenyl ether, and so on) are scattered. The health and environmental consequences are even worse when this e-waste is shipped to poor and emerging countries that have lower standards in their environmental, health and labour laws.

It is estimated that 200 to 250 million tonnes of Waste Electrical and Electronic Equipment (WEEE) with a low recycling rate are generated worldwide, growing at a rate of 3 to 5 per cent (Guillaume, Benjamin, and Vincent 2022). In Europe, it is estimated that 11 million tonnes of electrical and electronic equipment (EEE) were put on the market in 2019, and just 4.49 million tonnes were collected in the same year (Eurostat 2022a), with a high percentage of WEEE not being collected. In 2008 it was estimated that between 16% to 38% of WEEE were exported (Dodd et al. 2020), sometimes illegally, with a 10% estimation (Forti et al. 2020). In a recent survey, only 28% of respondents tracked their WEEE or equipment life cycle (Davis et al. 2022).

Given the large amount of electronic waste generated in data centres worldwide, circular economy opportunities arise. The global trend is to move towards hyper-scale data centres due to their lower costs and greater efficiency. However, they require shorter refresh cycles than traditional ones. This is an opportunity for circular economy strategies, as many other data centres may use the equipment without compromising performance (Fenn and Fesch 2020). A recent study states that if circular economy practices are implemented, 24% of CO2 equivalent may be saved thanks to manufacturing half of the servers (Fenn and Fesch 2020).

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[8] Data centre Tier definitions explain the infrastructure required for data center operations. There are different Tiers according to the system availability needed. These classifications are methods for comparing the performance of one site infrastructure against another. https://uptimeinstitute.com/tiers

2.5 SOCIAL CONCERN

In the first stages, the arrival of data centres in small towns and remote regions has been embraced in anticipation of local job creation and skills development. It nurtures hopes of alleviating local economic, demographic, or social crises, with examples in Athenry in Ireland and Gröningen in the Netherlands (Libertson, Velkova, and Palm 2021).

When asked about data centres, people/communities in Nordic regions had a general awareness of the functions of data centres but had thought little about data centres per se. Their first concern was about the uses and misuses to which this data may be put, including security failure via hacking. However, participants trusted data centres themselves in terms of their security efforts. The second main concern was power consumption, consequent potential impacts on consumer electricity prices, and the eventual need to construct additional energy supply and distribution infrastructure. Others were most concerned about climate warming effects close to home or pollution from the energy supply. Subsidiary concerns mentioned by individuals included: the possible effects of sub-oceanic fibre-optic cables on marine mammals, issues of sufficiency, and there being no end to development (Sovacool, Monyei, and Upham 2022).

On the other hand, in countries where data centres are being widely installed, such as Ireland, there is a significant concern regarding fuel or electricity supply cuts and the environmental impact in terms of emissions, which may complicate the objectives of 80% renewable energy in the electricity supply for 2030. This is due to the grid overload problems, which made EirGrid exclude Dublin from installation of new data centres until at least 2028 (Swinhoe 2022). In Sweden, members of several different parties – government, enterprise, and individuals – have expressed concern about expanding data centre capacity due to the possibility of overloading the electricity grid and limiting other industries (Cappella 2022). Recently during the droughts in Europe and in the context of the energy crisis aggravated by the war in Ukraine, there has been great concern about energy and water consumption in the Netherlands (Judge 2022).

In general, countries are encouraging the construction of data centres at their borders with low energy taxes and security of electricity supply. Thereby discouraging data centres from installing renewable energy for self-consumption, thus worsening network capacity for other users, which may engender further consequences for local communities and regional businesses. On the other hand, on-site renewables in cities may supply a small fraction of the total data centre energy consumption. For example, let us consider the photovoltaic (PV) building-roof potential with a power density of 100 W/m2 (installation factor). It is much lower than the average power density of a data centre (4 kW/m2), covering less than 1% of the energy. A data centre power density of 0,4 kW/m2 may cover 3% of the energy.

2.5.1 Social digitalisation

The need for more data centres is related, among others, to the fact that every year the number of internet users participating in social networks and the time they spend on them increases. Fig. 15 shows the recent increase of individuals using the internet to participate in social networks in Europe, Ireland, the Netherlands and Sweden. It shows that 57% of Europeans used the internet for social networking in 2021 (Eurostat 2022b).

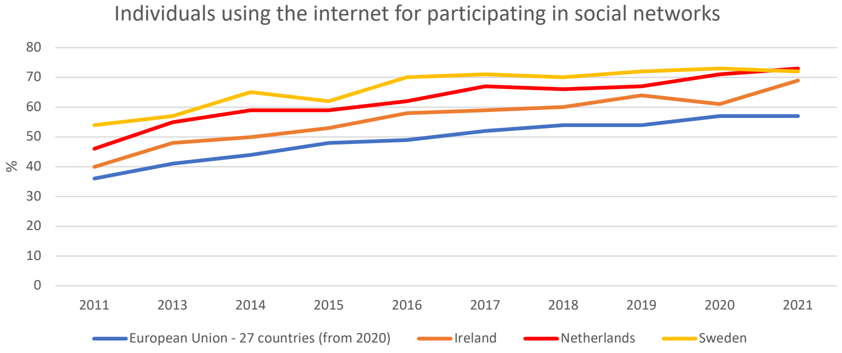

Fig. 15 Individuals using the internet to participate in social networks. Data obtained in (Eurostat 2022b).

The tools used to increase the number of users and time spent on social networks include personalised marketing, excessive push notifications to re-engage users, continuous flow of stories, variable ratio schedule[9], reward mechanisms, social reciprocity, gaming applications, virtual memories in applications and time-engaging mechanisms, among others (Coleman 2021). These tools create addiction among users, which has been reported to be similar to substance addictions (Ko et al. 2009), (Hormes, Kearns, and Timko 2014). This reinforces the recent requests calling for digital sobriety (Ferreboeuf 2019) and opens possibilities to regulate the sector to protect internet users and limit data volumes (Fig. 2). It should be noted that by 2023 consumers will be responsible for 74% of internet connections and the business segment for the remaining 26% (CISCO 2020).

Other health impacts are not considered in this study, such as the level of sedentary lifestyle and isolation behind personal screens. This can lead to an increase in obesity or the lack of development of social skills, as well as health problems due to poor postures (Farbiarz-Mas 2022).

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[9] Variable ratio schedule occurs when a response is reinforced after an unpredictable number of responses. This schedule creates a high steady rate of responding. Gambling and lottery games are good examples of a reward based on a variable ratio schedule.

3

POLICIES

The recent social concern and the lack of regulation have provoked the data centre sector to create self-regulatory initiatives for energy efficiency, carbon-free energy, water conservation, energy integration, server reuse and reparation. These initiatives aim to make data centres climate-neutral by 2030 (Climate Neutral Data Centre Pact 2022). A best practice guideline for the EU is a Code of Conduct on Data Centre Energy Efficiency guided by the JRC (European Commission 2022a). Another initiative related to hardware design in an open community is the Open Compute Project (Open Compute Project 2022).

The Green New Deal articulates digitalisation around sustainability, and it plans to examine the adoption of measures to improve energy efficiency and performance in terms of the circular economy of the sector. The European Green Deal also plans to assess the need to reinforce transparency on the environmental impact of electronic communications services, the adoption of stricter measures in the deployment of new networks and the advantages of supporting collection systems that encourage the return of devices.

The EU policy framework applicable to data centres is composed of strategies that establish the roadmap to meet the targets to achieve a sustainable consumption of resources and the decarbonisation of the economy:

- The Digital European Strategy states that data centres and telecommunications will need to become more energy efficient, reuse waste energy, and use more renewable energy sources. They can and should become climate neutral by 2030. How ICT equipment is designed, bought, consumed and also recycled matters. Beyond the energy efficiency requirements of ecodesign, ICT equipment must become fully circular - designed to last longer, adequately maintained, contain recycled material, and easily dismantled and recycled (European Commission 2020b).

- The European Strategy for Data seeks to materialise the vision of a single data market in the shared space. Environmental objectives include the decarbonisation of the economy and support for the priority actions of the Green Deal on climate change, circular economy, zero pollution, biodiversity, deforestation and guarantee of compliance (European Commission 2020a).

- The "Fit for 55 package" considers data centres in the field of energy efficiency, expressly the obligation to publish, every year, starting in 2024, information on their energy consumption. The Commission will publish this information in a public database (Council of the EU Press release 2022).

- The EU Strategy for Energy System Integration points to the potential of data centres and the reuse of waste heat by connecting it to district heating networks, energy performance accounting and contractual frameworks as part of the revision of the Renewable Energy Directive and the Directive 2012/27 on energy efficiency (European Commission 2020c).

- The Raw Materials Initiative, the strategy for tackling the issue of sustainable access to raw materials in the EU, is necessary to implement in digitalisation and has a direct link with the data centre industry.

Still, the legislative framework is composed of directives and regulations. The Directives set out goals that Member states must achieve, but it is up to the individual countries to decide how to achieve them. At the same time, regulations must be applied directly in their entirety by Member states. Some directives and regulations in the European Union consider digitalisation and the impact of data centres, as shown below:

Energy efficiency

- The main obstacle to including a data centre regulation in the Directive 2012/27 on energy efficiency (Directive on energy efficiency) is the difficulties in measuring some intangible aspects associated with cloud computing. Nevertheless, the Directive on energy efficiency points out one of the aspects with significant potential in terms of energy efficiency: the use of waste heat in district heating and cooling infrastructures. The Directive on energy efficiency states that Member states shall promote efficient heating and cooling systems, and the potential for developing local and regional heat markets shall be considered.

- To address the problem of monitoring energy waste from data centres, the Proposal for a Directive of the European Parliament and of the Council on energy efficiency states that Member States should collect and publish relevant data for the energy performance, water footprint and demand-side flexibility of data centres with a power demand of at least 100 kW. Data collection must be based on a standard Union template and ensure that waste heat is utilised when it is technically or economically feasible. This information should be used to establish sustainable indicators on energy efficiency, renewable energy sources, reuse of waste heat, cooling effectiveness, carbon usage, and freshwater usage. In addition, Member states should encourage data centres' owners and operators of 1 MW or more to adopt the European Code of Conduct on Data Centre Energy Efficiency. Moreover, by 2025 the Commission should create minimum performance standards for data centres.

- To promote the use of waste heat and cold from data centres, the Proposal for a Directive amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652 introduces the obligation for the Member states to facilitate the use of waste heat and cold through a coordination framework involving industrial and tertiary sector enterprises generating waste heat and cold that can be economically recovered via district heating and cooling systems, such as data centres.

Ecodesign

- Directive 2009/125/EC establishing a framework for setting ecodesign requirements for energy-related products (Ecodesign Directive) establishes minimum mandatory efficiency requirements for products allowed on the European market during its life cycle. The Commission Regulation (EU) 2019/424 laying down ecodesign requirements for servers and data storage products according to Directive 2009/125/EC and amending Commission Regulation (EU) No 617/2013 improves ecodesign requirements for servers and data storage products. It considers power supply efficiency, material efficiency requirements (for disassembly), and avoiding planned obsolescence (latest firmware after 2 years of the first sell to 8 years of the last sell, security firmware at least 8 years after the placing on the market of the final product), maximum Idle state power, minimum active state efficiencies, weight range for cobalt in batteries, neodymium in HDD, specific operating conditions to ensure free cooling, and testing the equipment to operate in extreme conditions. Upcoming a review of ecodesign requirements for computers and computer servers (2022).

- The Commission Regulation (EU) 2021/341 amending Regulations (EU) 2019/424, (EU) 2019/1781, (EU) 2019/2019, (EU) 2019/2020, (EU) 2019/2021, (EU) 2019/2022, (EU) 2019/2023 and (EU) 2019/2024 concerning ecodesign requirements for servers and data storage products, electric motors and variable speed drives, refrigerating appliances, light sources and separate control gears, electronic displays, household dishwashers, household washing machines and household washer-dryers and refrigerating appliances with a direct sales function modifies both. It establishes the criteria for the methodology in measurements. There is a new proposal for ecodesign for sustainable products regulation 2022/0095 (COD), repealing the Ecodesign Directive.

EU Ecolabel criteria

- Companies can choose to implement eco-labelling on their electronic products. In particular, the Commission Decision (EU) 2020/1804 establishes the EU Ecolabel criteria for electronic displays, with a list of requirements related to energy consumption, the environmental impact of toxic substances, use of resources, waste generation and social aspects.

Electronic waste

- Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE Directive). The directive is intended to regulate electronic waste collection, recycling and recovery. The WEEE Directive establishes that the Member States shall promote the design and production of electrical and electronic equipment, which take into account and facilitate dismantling and recovery, particularly the reuse and recycling of electronic waste, its components and materials. The Member States shall take appropriate measures to minimise the disposal of electronic waste as unsorted municipal waste and achieve a high level of separate electronic waste collection. The Directive requires the Member States to set up systems that allow end-users and distributors to return E-waste free of charge. To ensure environmentally sound treatment of separately collected E-waste, the E-waste Directive sets out treatment requirements for specific materials and components of E-waste and treatment and storage sites. This legal framework uses the principle of Extended Producer Responsibility, which requires producers to organise and/or finance their products' collection, treatment and recycling at the end of their useful life. The increased amount of processed E-waste must be accounted for and reported to the competent national authority. Each EU Member State, plus Norway, Switzerland and Iceland, have implemented national legislation according to the conditions of each country (Farbiarz-Mas 2018).

- Electronic waste shipments is regulated by Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste, which establishes procedures and control regimes for the shipment of waste, depending on the origin, destination and route of the shipment, the type of waste shipped and the type of treatment to be applied to the waste at its destination. There is a new proposal for new regulations on waste shipments to support a clean and circular economy in the EU.

Hazardous substances

- Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) considers avoiding hazardous substances in electronic equipment.

Taxonomy

- In line with the EU Taxonomy, the Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives. It includes some criteria for data processing, hosting and related activities.

Digital services

- The recently approved Digital Services package enables the European Commission to regulate online platforms of dishonest behaviours to users, which may be included in the definition of dark patterns avoiding the variable ratio schedule used by online platforms (European Council 2022). The European Commission proposed two legislative initiatives: the Digital Services Act (DSA) and the Digital Markets Act (DMA), and the main goals of both texts are to create a safer digital space and to foster innovation, growth and competitiveness (European Commission 2022).

Fluorinates greenhouse gases

- Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 regulates the use of refrigerants with Greenhouse Warming Potential.

Green Public procurement

- Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on public procurement and the technical report about Development of the EU Green Public Procurement (GPP) establish criteria for data centres, server rooms and cloud services (Dodd et al. 2020).

4

CASE STUDIES

Three European case studies are examined below: Ireland, the Netherlands and Sweden. The impacts generated by their data centres and the specific national legislation that applies to them are analysed.

4.1 IRELAND

Ireland's temperate climate helps reduce the amount of energy needed to cool servers, and its corporate tax rates (among the lowest in the world) and friendly regulatory environment make Ireland attractive to big companies. Furthermore, Ireland is ranked 28th in the world for data centre investment by Arcadis (Arcadis 2021). Related to WEEE, in 2019 Ireland generated 93 kt of E-waste and collected 52 kt (Forti et al. 2020).

Ireland has started to publish country-level data centre energy consumption estimated in recent years; energy consumption has more than tripled since 2015. The official statistics state that data centres' electricity consumption is 3.99 TWh, 14% of total electricity consumption (Central Statistics Office 2022). EirGrid, the grid operator, has recently published that data centres and new tech loads' electricity consumption is 5.3 TWh, 16.7% of total electricity consumption in 2021. By 2031 data centres and new tech loads will represent 28% of electricity demand in Ireland (EirGrid and Soni 2022), see Fig. 16.

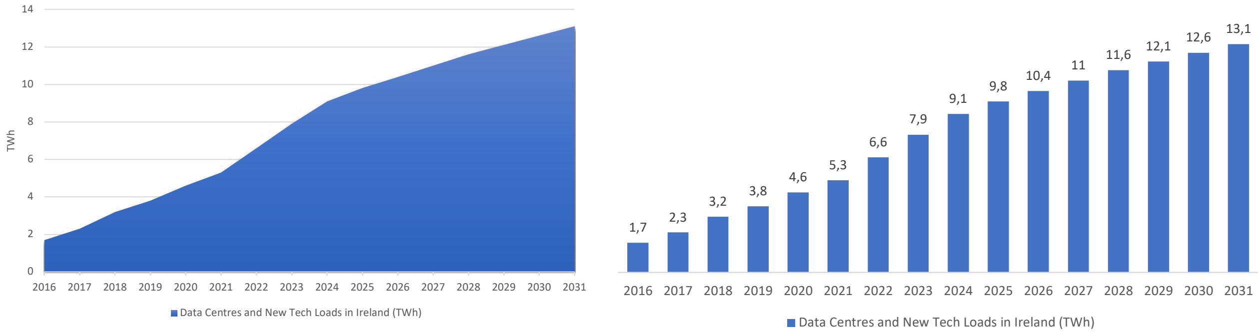

Fig. 16 Data Centres and New Tech Loads in Ireland. Data obtained in (EirGrid and SONI 2022)

The growing Irish demand for electricity from data centres has worried the grid operator. The Commission for Regulation of Utilities (CRU) warned that a surge in data centres growth could result in rolling blackouts asking for a temporary ban on new data centres. Later they withdrew their demands due to a "constructive engagement with industry stakeholders", but EirGrid excluded Dublin until at least 2028 for building new data centres due to overload problems (Dan Swinhoe 2022). EirGrid recommends their installation in other less congested areas and with a greater penetration of renewable sources.

Recently there was asocial concern related to a new data centre regarding pollution and energy intensity. Ennis's new data centre developer stated it would create 250 permanent jobs and 1200 temporary ones. The centre would comprise six two-story buildings. It would be supplied with 18 natural gas engines and 66 diesel backup generators, emitting 657,000 tons of CO2 per year, which represents 1.1% of global GHG emissions for Ireland (EPA 2022).

4.1.1 Legal and political framework in Ireland

The Irish government has been considering imposing a moratorium on the construction of new data centres in the country. Still, the government has finally ruled out this option and opted for more restrictive measures for data centres to be located in this country.

In July 2022, the government adopted a statement on the role of data centres in Ireland's business strategy, which lists six principles for achieving sustainable data centre development in Ireland. A preference is given to data centres that consider these principles based primarily on energy efficiency and renewable energy sourcing. In short, the document establishes a preference for those data centres that:

- are associated with the country's economic activity (economic impact principle),
- make efficient use of the electricity grid and demonstrate the additionality of their use of renewable energy (grid capacity and efficiency principle and renewables additionality principle),
- have the potential to co-locate a renewable generation or advanced storage facility with the data centre (co-location principle or proximity to a future-proof power supply),
- can demonstrate a path towards decarbonization and the provision of zero-emission data services (principle of decarbonized data centres by design),
- and provide opportunities for SME participation and deliver community benefits (SME access and community benefits principle).

The 2021 Climate Action Plan envisages increasing the share of renewable electricity in the country to 80% by 2030. Considering its intensive electricity consumption, the data centre sector has much to contribute in this regard.

In November 2021, the CRU Decision for System Operators was published regarding the processing of grid connection of data centres, which allows companies in the data centre sector to connect to the electricity grid subject to certain conditions, such as on-site generation and/or battery storage for new data centre connections, so that they can meet their own demand. In addition, in line with the country's climate targets, to move towards decarbonization of the sector, this generation should also be capable of running on renewable sources, including renewable gas or green hydrogen when supplies become more available.

The recent statement on the role of data centres in Ireland's business strategy notes the importance of capacity in data centre energy management (flexibility services), which refers to the ability of data centre facilities to alter their electricity demand or generation, either by controlling their internal processes (heating, cooling) or by using on-site storage or generation devices, especially at those times when the electricity grid is under pressure from peak demand.

Also, with the new principles for the sustainable development of data centres, Corporate Power Purchase Agreements (CPPAs) take on a relevant role in decarbonising the power sector. Through these agreements, data centres can purchase renewable electricity from renewable electricity generators, which in turn is an instrument for financing renewable generation projects. To this end, the location of data centres near renewable generation facilities is key. Nevertheless, CPPAs are a controverted instrument because it does not imply physically consuming renewable energy from the grid, serving more as a balance in the company's accounts.

The statement on the role of data centres in business strategy highlights the potential for data centres to contribute to the grid by providing waste heat to urban facilities such as commercial establishments or homes, thus decarbonizing the local energy system and reducing costs. The government's policy will facilitate the use of this waste heat and promote the figure of the pro-sumer. An example of this is the project to reuse waste heat from Amazon's data centre to supply heat to South Dublin County Council buildings and the TU Dublin-Tallaght campus through the Tallaght District heating system.

In conjunction with stakeholders, the Sustainable Energy Authority of Ireland (SEAI) is considering providing an enhanced electricity emissions reporting framework for Large Energy Users (LEUs), such as data centres, following the Climate Action Plan 2021.

4.2 NETHERLANDS

The Netherlands is one of the leaders in Europe in data centre installation. Recently it was ranked as the 19th country in the world best suited to invest in data centres(Arcadis 2021). The total data centre capacity is 590 MW. The number of data centres has declined for years because small Dutch data centres are closed and migrated into a few larger ones (Vermeulen and Madsen 2021).

The Netherlands has started to publish data centre energy consumption in recent years (CBS 2021). Dutch data centres consume 3.2 TWh of electricity, i.e. 2.7% of Dutch's electricity consumption (Dutch Data Centre Association 2022), almost doubling electricity consumption since 2017, see Fig. 17. The water usage is one million m3 (CBS StatLine 2022), which implies 0.08% of tap water consumption, with a WUE of 0.3125 l/kWh.

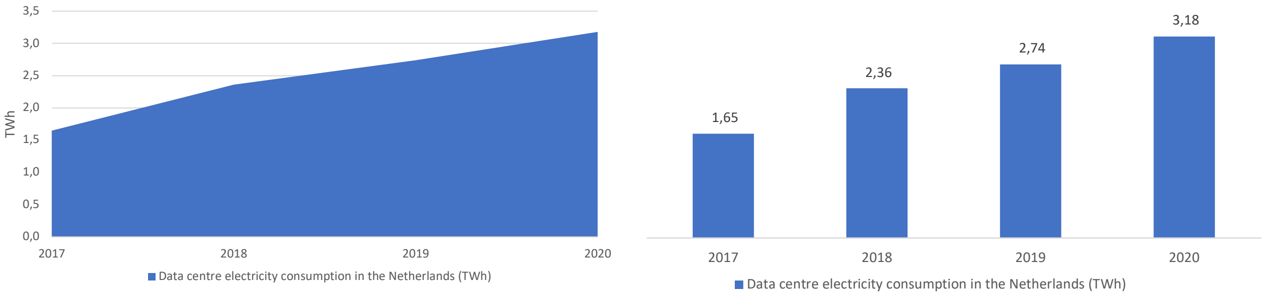

Fig. 17 Data centres electricity consumption in the Netherlands. Data obtained in (CBS 2021), (Dutch Data Centre Association 2022)

Dutch data centres buy most of their energy from renewable sources through PPAs (86%). However, on the other hand, by monopolising renewable generation, they make the rest of the electricity in the mix more polluting for the rest of the consumers if they do not promote the direct installation of renewable sources (Vermeulen and Madsen 2021).

There are some examples of energy integration. Fifty per cent of data centres store or reuse residual heat. Waste heat from data centres is used 1,300 apartments in Amsterdam Science, in some 40 office buildings on the High Tech Campus in Eindhoven or a swimming pool, school and nursery in Aalsmeer. Soon about 2,500 homes will be added in Groningen. However, this could be much more if restrictive regulations were amended according to DDCA (Dutch Data Centre Association 2022).

Among Dutch data centres, 17% do not use water, 17% use greywater[10] and 65% use drinking water (Vermeulen and Madsen 2021). Water consumption in Microsoft facilities of 78 million m3 has recently raised social concerns during the recent droughts in the Netherlands (Judge 2022). Microsoft states that the WUE of its new facilities was 0.08 l/kWh (lower than the Dutch's average), although they were designed for an efficiency rate of 0.01 l/kWh (Microsoft 2022).

Regarding WEEE, 8% of data centres offer a full-service recycling solution, 21% stimulate recycling, 29% offer third-party solutions for recycling and 42% play no role in recycling (Vermeulen and Madsen 2021). In 2019 the Netherlands generated 373 kt of E-waste and collected 166 kt (Forti et al. 2020).

The Open Compute Project enables the information of a data centre facility in the Netherlands, called "maincubes AMS01", located in Capronilaan 2 1119NR Schiphol-Rijk, with an area of 4,400 sqm, 4.7 MW of IT power, and a PUE<1.6. The cooling system does not use water and consists of a front-to-back system, with hot/cold aisle containment for all cabinets in white space. Immersion cooling is also available. The data centre supplies renewable energy (Open Compute Project 2022).

4.2.1 Legal and political framework in the Netherlands

The dutch government has announced some measures to control the unsustainable expansion of hyper-scale data centres, taking into account territorial planning and the consumption of resources.

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[10] Greywater is used water without toxic chemicals or excrements.

The *Spatial Strategy for Data Centres 2030* identifies the weakness of the sector at the same time that establishes a roadmap to keep the leadership of its data ports. The Strategy differentiates between small data centres (with a surface of 500 and 5,000 m2 and low energy consumption, less than 2 MW) and hyper-scale data centres (with a surface of 2,000 and 50,000 m2 and high energy consumption, from 1 to 25 MW). The location depends on factors like size or energy consumption. Some parts of the Amsterdam Metropolitan Area are adequate to locate clusters of hyper-scale data centres, and Almere, Lelystad, Zeewolde or Droten could be alternatives to their expansion.

To meet the targets fixed in the Klimaatakkoord, the strategy remarks the necessary location of data centres near renewable energy generation, as well as the accomplishment of sustainability requirements like installing solar panels on roofs and facades.

Based on the aforementioned Spatial Strategy for Data Centres in 2030, the recent National Strategy for Spatial Planning and Environment (Nationale Omgevingsvisie - NOVI) has been adopted, which seeks to encourage a selective growth of data centres in the country, for which it establishes conditions that must be cumulatively met before installing a data centre in a given location, namely: 1) that the energy demand can be sustainably met through existing or future energy networks; 2) that the supply of waste heat to district heating networks is possible; 3) that the requirements imposed by market participants for digital connectivity are met.

To facilitate the transition to this new model of selective growth of data centres in the Netherlands, in February 2022, the National Interim Decision to Prevent Hyperscale Data Centres was adopted, which postpones the creation of hyper-scale data centres (moratorium), understood as those data centres or set of structures that operate collectively with the function of providing support for transport or storage, whose extension exceeds 10 hectares and electrical power exceeds 70 megawatts. The validity of this decision is limited to nine months and applies only to hyper-scale data centres.

The province of North Holland (Noord-Holland) has been the first to adopt its own Data Centre Strategy for 2022-2024. According to the Strategy, new data centres may only be established in the industrial areas of Amsterdam, Haarlemmermeer and Hollands Kroon. They must first agree with the province on landscape integration, energy and water consumption, and the use of waste heat through appropriate spatial and environmental planning. Likewise, the risks arising from climate change, such as flooding or water shortages, must also be assessed in environmental planning. This Strategy sets out the foundations for sustaining the data centre sector's growth.

At the local level, the policy of the municipality of Haarlemmermeer limits the current growth of data centres in certain zones through a general zoning plan. Amsterdam (2020-2030) focuses on the environmental sustainability of data centres rather than on specific data centre zoning, including spatial integration measures for data centre buildings, energy efficiency and security, reduction of freshwater consumption, utilisation of waste heat through district heating networks, renewable energy generation, and monitoring and evaluation of the development of data centres in the municipality.

4.3 SWEDEN

The nordic region is seen as an ideal location for data centres, given adequate land, cold temperatures for natural cooling and clean sources of energy (Sovacool, Monyei, and Upham 2022). In addition, Sweden offers low energy prices and low taxes on data centres for electricity usage. Sweden is also well connected with submarine cables with Denmark and the Baltic States. Thus, the global consultancy Arcadis named Sweden as the best place in Europe for data centre investments (followed by Norway, Denmark and Finland) and the 4th in the world (Arcadis 2021), so a significant expansion of data centres is expected in the country.

Sweden contains several data centre clusters throughout the country, providing plenty of colocation opportunities. Sweden's primary colocation data centre markets are Stockholm, Malmo, Gothenburg, Lulea, and Linkoping. There are 81 Swedish data centres. Most of these colocation facilities are located in and around Stockholm.

Swedish colocation facilities provide over 122.54 MW of power and range rack density options from 3 kW to 20 kW. Their PUE, energy efficiency indicator, is between 1.07 and 1.70; the average PUE for Swedish data centres is 1.37 (Cloudscene 2022), and many data centres use waste heat in district heating networks. Sweden also has the world's first carbonnegative[11] data centre built by EcoDataCentres in Falun (Emily Holbrook 2018).

On the other hand, as well as in Ireland, several different parties in Sweden have expressed concern about expanding data centre capacities (Nicole Cappella 2022) because Sweden has been experiencing a grid capacity deficit since 2015. The main reasons are urbanisation and new industries and data centres. These capacity problems induced by data centres are negatively affecting other industries, with shortfalls in some regions of the south of Sweden and no warranty for new required electricity demands from the DSO to the expansion of existing facilities (Libertson, Velkova, and Palm 2021).

The Open Compute Project enables the information of a data facility called Hydro66 Hydrogränd 2 – Hall 1. It is located in Hydrogränd 2, Boden, Sweden 961 43. It has an area of 500 sqm, 1.6 MW of power IT, direct free air-cooled front to back with hot/cold aisle containment for all cabinets, and energy supply from 100% renewable hydropower with a flywheel UPS. Its PUE is lower than 1.08 and consumes 0.059 litres of water per kWh. Its Carbon Usage Effectiveness is 0.0428 kgCO2/kWh (Open Compute Project 2022).

Another example is the data centre Stockholm SWE01: SIF DC. The complex has an IT load of 11.2 MW, generating excess heat that Stockholm Exergi uses to heat local homes. It is a 6,000 m2 data centre and hosts up to 40kW air-cooled infrastructure or over 100kW for liquid cooling infrastructure to meet the growing demand for large-scale computing. Its capacity is up to 600 racks. It is supplied with carbon-free energy, which means that its energy is free from pollution, but it is backed up with diesel generators (atNorth 2021).

Related to WEEE, in 2019 Sweden generated 208 kt of E-waste and collected 142 kt (Forti et al. 2020).

4.3.1 Legal and political framework in Sweden

In April 2018, the Agreement on Swedish energy policy was adopted, setting the target for the Swedish economy to be climate neutral by 2045. Although the electricity generation in Sweden is almost decarbonised, the government cut off the subsidies destined for nuclear power to discourage this energy source. Traditionally, Sweden has decided to promote energy efficiency and reduce its carbon emissions by imposing taxation, such as energy and CO2 taxes. Sweden's energy mix is composed mainly by hydropower (42%), nuclear (31%), wind (16%) and other sources such as biofuels (6%).

On July 2022, a ban on extracting coal, oil and natural gas in Sweden entered into force. It proposes amendments to the Swedish Environmental Code and the Minerals Act. It includes a ban on the extraction of coal, lignite, crude oil, shale oil and natural gas in the same way that has been done with uranium, as well as tighter rules for extraction from alum shale.

The International Energy Association in the report Energy Policies of IEA countries, Sweden 2019 Review recommends boosting 4G heating urban systems and integrating it into smart urban grids.

The Broadband Strategy "*A completely connected Sweden by 2015*" points out the necessity to develop integrated electric grids to face the challenge to the capacity of the whole infrastructure in intensive demand of energy periods. However, in light of recent changes in the government, a drastic change in the country's energy and climate change policy could be expected. This shift in Swedish policy is beginning to be felt with the decision to abolish the Ministry of the Environment to integrate it into the Ministry of Energy, Enterprise and Industry. In addition, the energy crisis aggravated by the war in Ukraine and gas supply cuts have prompted the construction of new nuclear reactors in order to assure energy supply. Additionally, the network of charging points for electric vehicles will be expanded. For the time being, it could be expected that nuclear energy will play a more important role in the path towards decarbonisation.

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[11] The waste heat is used externally (this way the waste heat consumer do not use fossil fuels to heat), and as the data centre uses renewable energy to supply its electricity demand, the overall impact reduces the carbon emissions.

4.4 IMPACT OF DATA CENTRES IN THE CASE STUDIES

We have evaluated the impacts of data centres in Ireland, the Netherlands and Sweden, considering their respective electricity mix[12].

Ireland: Irish electricity mix is 29% provided by renewable energy with an emission intensity of 281 gCO2/kWh (EEA 2021), so for a new data centre of 1MW IT power connected to the grid, there would be 3,854 tons of CO2 emissions per year, with a material intensity of 423 kg every 3 years.

Netherlands: 18% of electricity consumed in the Netherlands comes from renewable sources (PBL Netherlands Environmental Assessment Agency 2020). The emissions intensity in the Dutch grid is 333 gCO2/kWh (EEA 2021). Thus a new data centre of 1MW IT power connected to the grid, there would be 4,568 tons of emissions of CO2 per year, with a material intensity of 423 kg each 3 years. If a Dutch grid carbon intensity higher than 516 gCO2/kWh is considered, as Nowtricity states (Nowtricity 2022), total emissions would account for 6,269 tons of CO2 per year.

Sweden: Sweden's total electricity generation from renewable sources is 59% (Swedish Energy Agency 2021), with an electricity carbon intensity of 8.8 gCO2/kWh (EEA 2021)[13]. Thus, a new data centre of 1MW IT power connected to the grid would generate 110 tons of CO2 per year, with a material intensity of 423 kg each 3 years.

Fig. 18 compares a server life cycle of 3 years for each country. As discussed above, if energy production sources are low in CO2 emissions, the associated climate impact is lower, which is the case for Sweden.

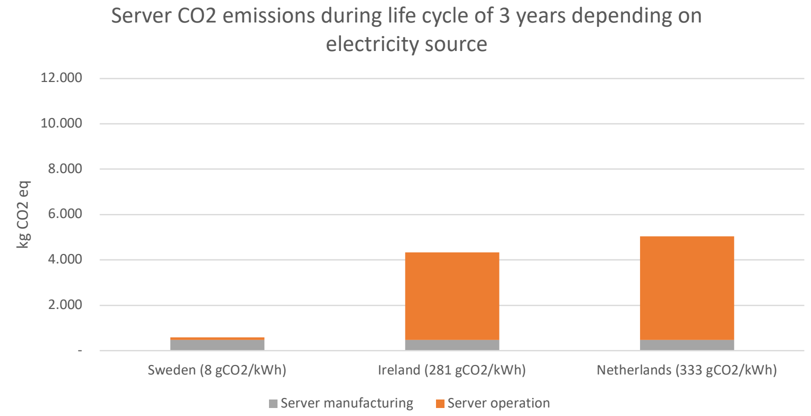

Fig. 18 Server CO2 emissions during a server life cycle of 3 years for Sweden, Ireland and Netherlands.

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[12] In order to make a comparison between the electricity systems, calculations have been made on the basis of carbon emissions. Other environmental impacts due to radiation or the use of waste for electricity generation have not been considered, but this does not mean that their impacts are not important.

[13] Although CO2 emissions in electricity generation are low in the case of Sweden, there are other environmental impacts such as radiation from nuclear power plants that have not been taken into account in this study.

5

POLICY CONSIDERATIONS

We have compiled several considerations to reduce the impact of data centres. Some of them are already covered in the European directives and national legislations discussed above. The first aspect to be mentioned is that data was difficult to collect. The literature reviewed generally agrees on the necessity of data transparency and creating databases with public information. The creation of a scientific observatory and committee capable of providing consensus and peer-reviewed information to the European Commission on digital technology's environmental and health impacts is also agreed. This is observed through the recently Proposal for a directive on energy efficiency.

Below is a list of best practices to be applied in data centres, divided into general aspects and specific measures related to energy, cooling, raw materials and user protection.

GENERAL ASPECTS

- Promote **mandatory reporting to public authorities** to allow data transparency (energy consumption, energy sources, use of materials in servers, water usage, LFA). Sustainability and Governance ESG reports should be mandatory for all data centres, with global carbon accounting and reporting of scopes 1, 2 and 3. The use of digital services should thus be included in the GHG emissions reporting standards. Regarding material use, the Proposal for a directive on energy efficiency does not consider materials in servers, and Regulation (EU) 2019/424 only considers two materials. If all or at least the most important materials (i.e. critical raw materials) were reported, it would be possible to carry out accurate life cycle analyses, as proposed by the Code of Conduct on Data Centre Energy Efficiency.

- Ensure **equitable taxation schemes** for data centres (avoid tax incentives and exceptions by countries and promote higher taxation on higher turnovers in data centres or use of resources).

- Member States should develop **plans and strategies to control the expansion of data centres with zonification criteria**, taking into account the impacts and risks of climate change (Lawrence 2021). This is being regulated in Amsterdam and Frankfurt. Plans should consider the data centre's contribution to the economy, local employment, the potential to generate renewable energy and the opportunities and benefits it provides to the community.

- Promote **tax incentives to reduce the environmental footprint of data centres**. For example, last year France approved Law No. 2021-1485 of November 15, 2021, aimed at reducing the environmental footprint of digital technology, which benefits with a reduced rate those data centres that implement good practices such as the recovery of waste heat generated in their facilities. Additionally, tax incentives could be put in place for companies embracing open code practices, thereby enhancing energy efficiency of computing. At the same time, apply **higher taxes for data centres which do not apply the best standards** or do not follow the Code of Conduct on Data Centre Energy Efficiency. Furthermore, the code of conduct is focused on 1 MW data centres, but its application should be encouraged to all regardless of size, even more with the recent surge of edge data centres (PwC 2019).

- Apply **Green Public Procurement (GPP) Criteria for data centres**, server rooms and cloud services and promote CBA (Community Benefit Agreements) between the project developer and the community where the project is built.

- **Avoid overprotection schemes and TIER IV levels**[14]. Data duplication only if necessary to avoid the vast amount of data collection when designing for the worst-case scenario. Reduce component redundancy when possible in data centres design, establishing standards for which kind of data centre or information may be duplicated according to its utility.

- At the same time, **enhance the resilience of data centres, through monitoring and preventive maintenance**, in order to reduce the impact of an incident, such as an interruption in the power supply (TechUK 2021), encouraging to have on-site generation and/or battery storage sufficient to meet its own demand, capable of running on renewable sourced fuels.

- Data Usage: **Incentives for automatically deleting unused data over time** should be considered to avoid storing large amounts of useless data (using mechanisms such as the CO2 market or progressive rates associated with data use).

- Apply **cryptocurrency mining restrictions** and incentive the migration crypto's operation to **proof-of-stake instead of the currently used proof-of-work** mechanism to perform the validation function[15].

- Increase funding for **research and development** for better use of energy and materials and next-generation computing and communication technologies.

- Consider joint work on legislation for potential seabed data centres. To this end, it is necessary to assess the advantages (as temperate climate or renewable energy capacity) and disadvantages offered by this new location for data centres compared to traditional data centres located on land, taking into consideration the impact that could be generated on marine ecosystems. This trend also opens up a new line of debate about the legal loopholes that could occur in international waters.

ENERGY

Energy supply:

- **Renewable power supply in electric grids**, assuring PPAs with proximity providers to allow for a physical integration with renewables and integration of more renewable capacity. New renewable energy power installation should be promoted, for example, mandatory new renewable energy supply a % of a data centre's demand must come from new renewable installation and must be within a radius of X kilometres, or self-consumed, to avoid monopolising renewable sources and making the grid more pollutant for the rest of consumers). The Proposal for a directive on energy efficiency considers the use of indicators for energy sources but does not consider the proximity.

- **Advanced use of energy storage devices**, with fossil fuel-free backup.

- **Stop energy tax incentives to data centres** as this limits other users' access to the grid with overload problems and discourages data centres from installing renewable energy for self-consumption. In turn, incorporate incentives to data centres that contribute to grid capacity with energy generation and demand management. However, the purchase of renewable energy only accounts for part of the carbon footprint of data centres, as the energy sources used for the extraction and manufacture of the components and materials used must also be assessed to avoid incurring in greenwashing practices. Of particular relevance in this regard is the classification of activities and sustainability criteria contained in the Delegated Regulation (EU) 2021/2139, which specifies when the activity of data centres can be considered as contributing to climate change mitigation and not causing significant harm to any of the environmental objectives, including aspects such as end-of-life recycling of electrical and electronic equipment.

- Create a **dedicated assessment agency** to analyse which activities deserve to have priority when electricity supply is limited. This agency must avoid unequal power relations

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[14] A Tier IV data center has several independent and physically isolated systems that act as redundant capacity components and distribution paths (https://uptimeinstitute.com/tiers)

[15] For more information, consult: https://www.iea-4e.org/wp-content/uploads/2021/12/4E-Policy-Brief-EDNA_14-010322.pdf

Energy use:

- Promote **labelling according to the energy efficiency of IT equipment and life cycle impact**, creating a standard with established metrics, assessment tools and methodology. These labels must be revised periodically. This is contemplated in the Regulation (EU) 2021/341. Moreover, the Proposal for a directive on energy efficiency contemplates that the Commission establishes minimum sustainable indicators on energy efficiency. Some European standards on energy efficiency and PUE are: (Climate and energy management EN 50600-TR 99, SC3 criterion, Environmental management TS 5; EN 50600-2-3, Good practices for refrigerating systems TS 7; EN 50600 –TR 99, norm EN 50600-4-2).

- Establish **guidelines for proper data centre installation** with recommendations and best practices, such as using direct current (DC) in data centres, modular Uninterruptible Power Supply for enhanced efficiency or the use of high-performance equipment and installation of devices for dynamic control of systems to improve efficiency at partial loads.

- Establish **mandatory energy audits** to ensure facilities comply with the main energy measures proposed in the Code of Conduct on Data Centre Energy Efficiency.

- **Harmonised taxation in Member States** to stimulate efficient energy consumption and achieve reductions in carbon emissions from energy consumption, e.g. through taxes on polluting fuels (Chitakasem 2020).

- **Financial support for energy efficiency measures** could be considered, especially for small and medium enterprise data centre operators. For instance, following measures such as shutting down or putting servers that are not in use into standby mode.

- Energy integration should be promoted. **Incentives for energy integration** may be attractive as there are currently no incentives for investing in such infrastructure, for example, lower taxation on the energy coming from residual heat and recognition of recovered and reused heat as an energy source that reduces emissions. The Proposal for a directive on energy efficiency contemplates that the Member States shall ensure that data centres of at least 100 kW of power recover waste heat when it is economically or technically feasible. Enacting a policy framework in Europe that facilitates and encourages any energy-intensive industry to pursue heat recovery and reuse projects in partnership with communities or businesses may be interesting. Some metrics for heat reuse are: ETSI ES 205 200-2-1 (ISO/IEC 30134-6:2021); EN 50600-4-6:2020 Part 4-6: Energy Reuse Factor.

COOLING

- **Improve the air management for cooling** to reduce the need for refrigeration with free cooling as the preferred option or liquid cooling avoiding water-cooling, for example, conduct studies on air flow management with computational fluid dynamics software.

- Use hot and cold aisle containment when air cooling to improve energy efficiency in cooling, i.e. do not mix the cold zone (the zone where the air is taken in for cooling) with the hot zone, the zone to which the air is released from the server.

- Increase allowable server room temperatures as it saves energy for cooling. Regulation (EU) 2019/424 establishes temperature thresholds to operate.

- Facilitate the **reuse of industrial water** and other non-potable water sources for cooling.

- Avoid refrigerants with Global Warming Potential, as Regulation (EU) 517/2014 stipulates.

RAW MATERIALS:

Manufacturing:

- Promote **Best Environmental Management Practices** (BEMP) for manufacturers.

- Require **source certificates of materials for data centres** and avoid using conflict minerals.

- Establish a **minimum amount of recycled materials** in new servers, making special focus on critical raw materials to reduce dependency.

- **Improve manufacturing processes** to rely less on carbon-based fuels and toxic substances. For instance, reduce the use of heavy metals in the production of IT components to decrease the carcinogenic effects of the manufacturing stage. Reduce perfluorocarbon emissions (PFC) in the manufacturing process of flash memories. At the same time, reduce gold and copper in components and the processes used in their refining to reduce long-term emissions.

- **Promote dematerialisation of designs** with virtualisation of servers and consolidation of data centres. Centralisation and economies of scale via cloud computing or hyper-scale facilities may have their counterparts as rebound effects if the impacts of storing are not considered for the user.

- **Avoid planned obsolescence in servers**, either in their hardware design or in changing software needs, extending the warranty to a minimum of years at least equal to the optimal refreshing time. Regulation (EU) 2019/424 states a minimum time for firmware actualisation.

Operation

- Encourage labelling for selecting **low-impact IT equipment**.

- **Extend the refreshing time**. Promote the design for extended refresh periods and an optimal timescale for hardware refresh regulating the refreshing time. Some methodologies establish an optimal refresh time (Bashroush 2018), such as the Eureca project.

End of Life

- Avoid policies that inhibit circular economy material flows and support policies to facilitate the **reuse and recycling of equipment**.

- Promote the **design for staged decommission**, allowing the replacement of only the parts that have come to their end of life instead of a total replacement (including cables). For instance, a minimum amount of refurbished servers in data centres could be established. The Ecodesign Directive 2009/125/CE and WEEE Directive 2012/19/EU tackle this issue. However, they should be made more specifically with standardised methodologies (for example with the NSF/ANSI 426-2019 environmental Leadership and Corporate Social Responsibility Assessment of Servers). Furthermore, **indicators for repairability and disassembly** should be created with a minimum requirement. There is a European standard related to this: UNE-EN 45559:2019.

- **Create second markets for IT products**. Some examples: Hyper-scale centres need better servers and may require faster refreshing. The equipment may be used in other sectors. Create standard certifications of quality and product origin for that second-life IT. At the same time, standardise hardware to facilitate reuse by promoting, for instance, Open hardware projects. Examples: Open Compute Project (OPC) benefits from innovations (Open Compute Project 2022) and shares designs for lower material usage and better energy efficiency.

- Invest in **research to optimise the current process** for obtaining precious metals in electronic boards and recovering critical and non-precious metals from electronic products/waste—investment in WEEE recycling plants. Start to think of electronics as resources to avoid the flow of electronics out of the borders and recycle them inside the borders, trying to avoid the illegal exports of WEEE.

- **Avoid the disparity criteria** and unite implementation and interpretation of norms at the State level for waste shipment regulation, as some WEEE is exported illegally. It is necessary to develop a more precise definition of electronic waste in order to avoid loopholes that promote illegal export to developing countries under the premise of WEEE reutilization, despite the fact that the exported materials are often irreparable and often end up in landfills where hazardous waste pile up.

PROTECTION OF USERS (THE INCREASE IN DATA DEMAND IS DUE TO USERS SOMETIMES BEING ADDICTED TO SOCIAL NETWORKS)

- Protect users from addiction mechanisms with control committees on the operation of platforms or applications. This may be included inside the definition of the dark pattern in The Digital Services package.

- Invest in education for consumer awareness activities about data addiction, associated environmental impacts, and energy use.

- Applying the recommendations above could substantially reduce the impacts of data centres. We have performed potential savings scenarios of CO2 emissions for a 1 MW data centre considering some of the following measures:

- The base scenario considers a PUE of 1.46, which is the average in the EU. A carbon intensity in the electricity production of 255 gCO2/kWh (EEA 2021). A server refresh period of 3 years.

- If an efficient PUE of 1.07 is considered, CO2 emissions could be reduced by 23%.

- If renewable energy is used, CO2 emissions could be reduced by an additional 72%.

- If extending the refresh time to 5 years is considered, an additional 26% CO2 reduction could be obtained.

- If circular economy practices are applied, an additional 16% CO2 emissions reduction could be achieved[16].

- If all the measures are applied, 87% CO2 emissions reduction could be achieved, see Fig. 19.

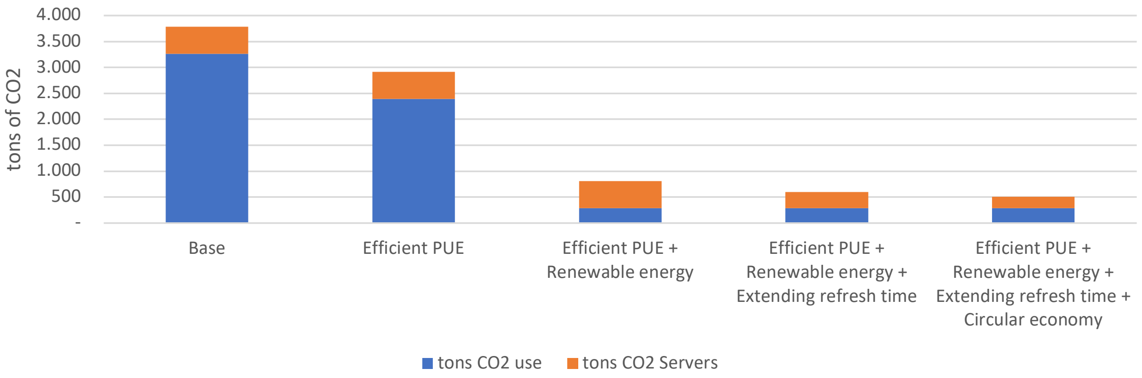

Fig. 19 CO2 emissions reduction potential for 1 MW data centre

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[16] Considering the study of (Fenn and Fesch 2020), that assumes that in if circular economy practices are implemented, 24% of CO2 equivalent may be saved thanks to manufacturing half of the servers.

6

CONCLUSIONS

The end of Moore's Law and a soaring data demand growth mean that all predictions expect exponential growth in energy demand. Every year, expectations for data centre energy growth are exceeded by reality. Arguably, in 5-10 years, current energy savings will not effectively counter the exponential growth in demand for data. Efforts must be directed towards:

- Mandatory standardised data collection and transparency.
- Integration of considerations for social concerns and overloading problems when designing data centres and establishing grievance mechanisms.
- Promotion of power supply from renewable sources to reduce the overall impact.
- Increasing efficiency for IT (computing, hardware, design, virtualisation, ect) in addition to PUE reduction and energy integration.
- Water conservation, avoiding the use of water for cooling.
- Low carbon emissions manufacturing of IT components and maximising the use of recycled materials, especially critical ones.
- Waste management of electronic equipment, recycling and reusing, extending servers' useful life, using a circular economy approach with mandatory standards at the EU and national levels.
- Avoid useless data.

In short, this report has stated that current EU policies are in line with the aforementioned good practices towards lowering the impacts of data centres. That said, transparency and traceability are still challenging for the data centre industry, and nowadays, it depends on the willingness and commitment of companies. The Proposal for a Directive on Energy Efficiency plans to articulate a legally binding framework that forces data centres to increase their transparency regarding their energy efficiency, use of renewable sources, reuse of waste heat and water usage. Nevertheless, appropriate standards to measure the sustainability of data centres need to be developed. A harmonized common framework to promote the use of renewable energies, for example, through taxation, will also be an asset. The WEEE and Ecodesign Directives tackle the issue of raw material consumption. Yet again, more specific standards for data centres should be provided to enhance the use of conflict-free minerals, material efficiency, equipment durability, the use of recycled parts and materials and promote reuse and recycling at the end of life. Finally, the social dimension of data use is becoming increasingly important due to the rapid growth in the volume of data, the question of the purpose of data consumption and the social addiction and health issues it generates. According to current trends, these issues will gain importance and will have to be addressed in future European legislation.

7

FIGURES

8

TABLES

9

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