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DATA CENTRES & THE GRID

GREENING ICT IN EUROPE

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List of Abbreviations

AI – Artificial Intelligence

BNEF – Bloomberg New Energy Finance

CCS – Carbon Capture and Storage

CPC – Contract Performance Clause

DC – Data centre

DCE – Data centre entreprise

EC – European Commission

EV – Electric Vehicles

EEA – European Environment Agency

EED – Energy Efficiency Directive

ERP – Enterprise Resource Planning

EU - European Union

GHG – Greenhouse Gases

GPP – Green Public Procurement

HDD – Hard Disk Drive

HD – High Definition

ICT – Information and Communication Technologies

IEA – International Energy Agency

IoT – Internet of Things

IP – Internet Protocol

JRC – Joint Research Center

LMP – Locational marginal price

MENA – Middle East and North Africa

ML – Machine Learning

NPV – Net Present Value

PPA – Power Purchase Agreement

PUE – Power Usage Effectiveness

REDII – Renewable Energy Directive

RES – Renewable Energy Supply

RTO/ISO – Regional Transmission Organization / Independent System Operator

SaaS – Software-as-a-Service

SDG – Sustainable Development Goal

UPS – Uninterruptable Power Supply

VRE – Variable Renewable Electricity

4K – Ultra-high Definition

EXECUTIVE SUMMARY

Executive Summary

Aim of the study

The main aim of this study is to provide regulatory and policy recommendations to frame the potential evolution of data centres (DCs) as active players in the European Union's (EU) energy system and to ensure adequate grid management and optimisation in the context of growing computing needs.

DCs are buildings or part of a building that host computer servers that run continuously to undertake internet related computing tasks. DCs often have an uninterruptible power supply (UPS) in the form of very short term battery supply. Larger data centres can also have back-up power generation. This allows them to continue to operate for a short period following a loss of power from the grid.

They are a key part of the information and communication technology (ICT) sector, which stands at the heart of the modern digital economy. The rapid adoption of emerging ICT technologies and paradigms (i.e., Internet of Things (IoT), cloud computing, artificial intelligence (AI), big data, data analytics, blockchain, 5G) contributes to the modernisation of our economy, from transport to manufacturing. During the health crisis, information technologies also demonstrated their contribution to the resilience of our societies. Digitalisation is itself one of the pillars of a smart energy system that facilitates decarbonisation.

Our discussion is framed within the 2021 European Climate Law and associated directives and regulations which seek to achieve climate neutrality (or net zero) by 2050 across the EU-27. This objective is shared with other European countries such as the UK.

Context around DCs and their future energy consumption

A large hyperscale DC can draw up to 100 MW peak from the grid. Currently DCs are a small but growing part of total EU electricity demand (estimated at 2.7% in 2018). However, under some projections this might rise significantly by 2030, especially in the context of falling total demand for overall energy but rising electrification.

This report discusses what drives DC energy consumption. We show how over the past decade the rise in electricity demand from DCs has been modest against a background of sharply rising demand for data and the growth of large-scale DCs, owing to significant efficiency improvements.

DC owners, such as Amazon, Facebook and Microsoft have also invested considerably in renewable power purchase agreements (PPAs) to cover the equivalent of their electricity demand with low carbon electricity. In addition, DCs are only responsible for around 30% of total ICT consumption.

Next, the report discusses the legal status of DCs, which is not well defined in law with respect to energy consumption. However, several energy-related EU directives do explicitly target DCs, usually as examples of high consuming sectors that are expected to respond to policy initiatives. The report also briefly discusses the different roles that DCs play within the energy system.

The report goes on to examine the extent to which Europe attracts DC investment, comparing a number of European cities on the basis of criteria such as quality and availability of electrical capacity, temperature, fiscal incentives, and proximity to data demand. This allows a better understanding of why DCs may cluster around particular cities that score highly on a number of desirable characteristics.

The report then discusses DC markets in Ireland and Denmark to demonstrate the importance of interconnection, renewable electricity shares, and the proximity of heat networks for longer term prospects in the DC markets that are currently favoured.

The report also explains what net zero energy policies imply for DCs. Like any significant electricity consuming sector, DCs cannot escape the pricing implications of net zero and its likely requirements for increased differentiation of connection, energy and ancillary services costs. This presents opportunities for DCs that can offer flexibility to a grid that will increasingly be dominated by variable renewable electricity (VRE).

Regulatory proposals which could affect DCs

The report continues with a discussion of the regulatory issues facing DCs at European level. The legal direction of travel seems clear: DCs will be increasingly targeted when it comes to energy efficiency measures and requirements to participate with third parties in achieving climate neutrality. In this context, the manner to regulate DCs under EU law must be made consistent across the different legislative acts. EU legislative and regulatory initiatives should also aim to foster synergies and mutual benefits from the integration of DCs within the energy system.

The report suggests that:

- When advancing regulatory proposals on DCs, a 'dynamic regulatory approach' should be favoured, based on a mix of legal instruments (legislation, guidance, standards, self-regulation) of both legally binding and non-binding nature.

- DCs could serve as role models for the regulation of energy intensive industries, without the need to necessarily be singled out. However, the size of the load may need to be reflected in both connection rules and connection agreements.

- EU regulatory intervention should prioritise the harmonisation of common definitions, principles, obligations and operating rules.

- As part of the alignment of regimes across the energy and telecommunications sectors, and keeping in mind security and resilience imperatives, one should assess carefully the extended scope of application proposed under the revision of the Network and Information Systems (NIS) Directive (to be replaced by a NIS2 Directive) and the relationship to the European Critical Infrastructure Directive.

- The integration of DCs into high-level energy planning processes should be further pursued.

- The Ecodesign Directive provides a legal basis for the further regulation of energy consumption at DCs, which could be used to reflect some of the (voluntary) adopted standards where there is a need for further harmonisation. It could also be used to regulate the more complex and modern DC entities, subject to amendments.

- The outcomes of this report support the approach of the new Energy Efficiency Directive (EED, proposed as part of the EU climate neutrality package) which suggests that all district heating and cooling systems should aim to improve their ability to interact with other parts of the energy system in order to optimise the use of energy and prevent energy waste by using the full potential of buildings to store heat or cold, including excess heat from service facilities and nearby DCs.

- Government procurement processes should be used to encourage the use of more environmentally sustainable DCs. Particularly, public authorities and publicly owned entities should be further encouraged to rely on the EU Green Public Procurement criteria for their use of DCs.

- The revision of the Energy Taxation Directive might be an opportunity for the European Commission to harmonise certain practices, at least in terms of minimum harmonisation, to eliminate energy tax breaks which subsidise higher DC energy consumption.

Conclusions

Overall, in Europe, DC energy demand is modest but growing. However, it is larger in some smaller European countries such as Denmark and Ireland.

Over the next ten years, European internet traffic is expected to grow, but the consequences for DC electricity demand are uncertain. This is because in recent years rising energy efficiency in DCs has largely offset the energy impact of rising data demand. The move to more efficient cloud hyperscale DCs is part of the explanation behind these efficiency gains. However this benign situation might not continue indefinitely. Therefore, it is unclear whether there is an issue with sustainable solutions for meeting DC energy demand in general across Europe.

There are emerging issues around some particular cities, such as Dublin, with large and growing DC clusters that may also have consequences for the national level electricity grid. This has increased grid constraints and could potentially result in increased cost to consumers if there are increased demands on electricity networks and should resource adequacy gaps emerge. It has also resulted in planning permission and siting issues over concerns about the availability of grid connection capacity, as well as political pressure to curtail DC investment in certain locations.

Pressure to better measure energy consumption is already manifesting within existing and proposed EU legislation and this trend can be expected to continue. A wider range of metrics for modelling DC electricity demand, and what drives it, is poor. The industry needs to make more information available so that there can be appropriate independent modelling of the end-to-end energy usage process in ICT.

COVID-19 does not seem to raise particular issues for DC energy demand, but climate neutrality does. Like any significant source of electricity demand, DCs will be subject to a range of European and domestic laws and regulations designed to encourage energy efficiency and the switch to clean energy, which are central pillars of climate neutrality.

Industry associations and industry standard setting bodies can (and already do) play a key role in spreading best practice on energy consumption and contribution to greater decarbonisation of the DC sector.

There seems little reason to negatively single out DCs in European law, given their need to have UPS and the potential for back-up generation and storage, unlike many other major commercial loads. This is because in places where DC demand is growing sharply, electricity grid issues are to do with the addition of any new large load, and hence can be addressed by regulations which target the load characteristics rather than the nature of the load's economic output.

Rather, a key test of whether energy law and regulation is effective will be to assess whether it encourages large loads - such as DCs - to facilitate the energy transition and energy system integration.

Issues encountered locally when introducing DCs in certain locations emphasise the importance of:

- Long term planning and investment into grid infrastructure;
- Visibility of load growth plans from DCs;
- Interconnection and network charges that fully reflect the system costs associated with new, large loads;
- Locational price signals via use of system charges for transmission and distribution; and
- Adequate price signals to encourage flexibility and the co-location of batteries, generation and loads.

The DC sector has the opportunity to take a lead in corporate citizenship towards carbon neutrality by actively facilitating the European energy transition and going beyond the letter of the law and regulation when it comes to innovation in energy reduction and co-operation with other actors in the energy sector. It is encouraging to see evidence that this is happening.

We suggest that DC operators can go further in terms of ensuring that large DCs are capable of contributing to system wide decarbonisation by appropriate configuration of their UPSs, onsite back-up generation, energy storage and energy management to increase grid-level flexibility. This remains an under-researched area for future development.

The ICT revolution and, implicitly, DCs are central to the future of the European economy. Indeed, there is great potential for ICT to contribute to wider decarbonisation via the use of data in energy to reduce energy use generally. The ability of other sectors such as transport to reduce their use of energy will depend on the substitution of data-intensive activities for energy-intensive activities, such as the use of video-conferencing instead of international business travel, relative to business as usual.

01

INTRODUCTION AND BACKGROUND OF THE RESEARCH PROJECT

1 Introduction and Background of the Research Project

With the adoption of the European Green Deal (European Commission, 2019a) and the European Climate Law (Regulation (EU) 2021/1119,[1] European Commission, 2020d), the EU aims to achieve one of the most ambitious climate plans worldwide: to become the first carbon neutral continent by 2050, with challenging objectives as early as 2030 – a 55% reduction in greenhouse gas (GHG) emissions compared to 1990. The strategy highlights a great number of policy and regulatory actions for the next five years. These include greening the ICT sector, taking into account the socio-economic activities accelerated by the health crisis (e.g., teleworking, telemedicine, distance learning[2]), and the rapid adoption of emerging technologies and paradigms (i.e., IoT, AI, cloud computing, edge computing, big data, data analytics, 5G, Blockchain).

As part of the European Green Deal, the European Commission also aims to improve the energy efficiency and performance of the digital sector as a whole and to accelerate the adoption of a circular economy model. Moreover, these concerns are concomitant with the move to finalise a European data strategy (European Commission, 2020a). Thus, the European Green Deal aims to address some of the issues raised by the twin challenge of a combined green and digital transformation. It outlines the internal challenge of these 'twin green and digital transitions'[3] where the digital sector should put sustainability at its heart, so that technology can enable the EU's climate ambitions.[4] The COVID-19 crisis has not altered these ambitions. On the contrary, one of the main objectives of the recovery plan is to accelerate progress on the Green Deal.[5] Indeed, the EU-27 agreed a net zero target for GHG emissions in 2050 in June 2021 as part of the new European Climate Law (Council of the European Union, 2021). This law aims to enshrine into law the EU's commitment to reach climate neutrality by 2050 and the intermediate target of reducing net GHG emissions by at least 55% by 2030, compared to 1990 levels.[6]

In response to the threats of climate change, some actors of the ICT sector have already developed ambitious plans to reduce direct and indirect emissions, in order to achieve climate neutrality (in general by 2040 at the latest, i.e., ahead of the EU's objectives).[7] Nevertheless, the energy footprint of some digital services is subject to intense debate (The Shift Project, 2019; Kamiya, 2019b). The

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[1] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 (European Climate Law), OJEU L 243, 9.7.2021, p.1.

[2] Global internet traffic jumped by nearly 40% between February and April 2020, at the height of the COVID-19 containment measures, driven by the growth of video streaming, videoconferencing, online games and social networks. Sandvine, The Global Internet Phenomena Report, 2020.

[3] Since the adoption of its Communication on the European Green Deal in December 2019, the European Commission has consistently referred to the 'twin green and digital transitions' including as part of the post-COVID-19 recovery plan. See the communications from the Commission: 'The European Green Deal', COM (2019) 640 final, 11 December 2019; and 'Europe's Moment: Repair and Prepare for the Next Generation', COM (2020) 456 final, 27 May 2020.

[4] The positions taken by the EU's highest authorities illustrate this "tension" between the implementation of the environmental and digital transitions: Executive Vice-President Margrethe Vestager, responsible for a Europe Fit for the Digital Age, said: "*The European Green Deal aims to make Europe the first climate-neutral continent by 2050. In this regard, we cannot let our electricity consumption go unchecked. A smarter and greener use of digital technologies are a key part in making sure Europe reaches its ambitious goa*l". While Commissioner for Internal Market, Thierry Breton, added: "*The global data volume will keep growing rapidly. That's why we are fostering suitable infrastructures for eco-friendly efficient cloud services and energy efficient data centres. Europe will be the epicentre of green technology*". European Commission, Green and Digital: study shows technical and policy options to limit surge in energy consumption for cloud and data centres, 9 Nov 2020.

[5] The health crisis has led to the Green Deal being included in the European recovery strategy: in the "Next Generation" plan, at least 37% of the EU funds must be used for green projects.

[6] For a detailed analysis of the different objectives and targets set in the Law, see the REDII report, section 2.1.1.

[7] In terms of decarbonation commitments, the information technology sector is among the most advanced: Ecoact, The Sustainability Reporting Performance of the DOW 30, September 2020.

growing role of IT in the organisation of our societies implies that, beyond the carbon footprint, we must keep an eye on electricity consumption, by ensuring efficiency gains and optimisation.

In this context, particular attention must be paid to the significant deployment of DCs. Hyperscale DCs grew from 259 to 597 globally between 2015 and 2020 (Statista, 2021). On the one hand, their energy needs are quite limited, at around 1% of global power consumption, rather stable in recent years due to energy efficiency improvements (Masanet et al., 2020) and accompanied by low-carbon sourcing efforts, especially through Power Purchase Agreements (PPAs).[8] In addition, DCs also offer system-wide efficiencies by enabling the transition to cloud-based services and reducing the need for on-premises DCs and servers. On the other hand, at local level (i.e., in some regions and/or cities), the concentration of DCs may induce significant electricity demand loads, challenging electricity grid management and requiring additional investments in infrastructures, both in the field of energy and telecommunications, in particular concerning the fibre network.

Various projections suggest that Europe is not immune to this phenomenon and that, while the development of the DC sector across the EU is not necessarily an acute concern, local density could become one, as is already the case in some regions. By 2030, DCs and other large users may consume 27% of Ireland's total annual electricity demand, according to EirGrid-SONI (2021. During the same period, in Denmark, industry and services power consumption may increase by about 3% annually, of which electricity demand by large DCs may account for 80% (Danish Energy Agency, 2019).

However, important developments underway resulting in optimised operations of DCs via electrical, heating and telecommunications improvements may reduce the impact of such evolutions. In that respect, DCs could be integrated with the energy grid – for example – of a smart city and act as an independent energy player, contributing to the energy needs of the urban area by trading energy flexibility services on the wholesale electricity/ancillary services markets. More generally, these facilities could also contribute to integrate renewable energy into local networks as DC batteries may present an opportunity to absorb power from the grid when supply outstrips demand, or to help local grid operators to manage their peak load.[9] Of course, such expectations must also be considered against the operational reality of DC management and will be conditional on the emergence of new economic models. The latter will depend on local parameters and are not expected to emerge on the scale of the Union as a whole. Moreover, it is confirmed from year to year that ICT companies are already major contributors to the development of renewable energy through PPAs (BNEF, 2020).

To date, the EU has relied on voluntary efforts to manage the ICT sector's energy needs. There is a European code of conduct launched by the Joint Research Centre (JRC) to help operators cut energy consumption (Bertoldi et al., 2017). Certain actors in the European DC industry are taking a proactive stance, in particular with the Climate Neutral Data Centre Pact launched in early 2021.[10] But this industry is quite heterogeneous in terms of performance, depending on different parameters, including the age of the equipment, which was confirmed by the publication of a major study sponsored by the European Commission in November 2020 on the energy efficiency of cloud computing (Montevecchi et al., 2020). This report seeks to highlight European perspectives in this field and to inform public policy orientations.

In this context, **the main aim of the present study will be to provide regulatory and policy recommendations to frame the potential evolution of DCs as active players in the EU**

[8] The top six corporate off-takers of renewables in 2019 were all ICT companies (BNEF, 2019).
[9] Depending on type of battery and frequency of charge/discharge. Also services required what is described is energy arbitrage, whereas fast cycling and frequency support from batteries may also be of value.
[10] This initiative brings together 54 data centre owners and 22 data centre and cloud industry trade associations in support of the EU's climate neutrality goal. For more information visit: www.climateneutraldatacentre.net

energy system and to ensure adequate grid management and optimisation in the context of growing computing needs. This is all the more pressing since the COVID-19 crisis will have considerably accelerated the development of remote activities, with potentially long-lasting effects, especially in the field of teleworking. Given that DC activity is likely to represent an electro-intensive sector in Europe into which massive investments will be channelled, it is essential to understand the diverse effects of the dynamic development of the DC industry over the past decade. In that context, the regulation of DCs could also serve as role model for other electro-intensive sectors, without necessarily needing to single them out in regulatory and legislative initiatives.

The rest of the study is organised as follows:

- Initially, we conduct an analysis of the determining factors of energy consumption and the carbon footprint of DCs by considering the elements relating to technical progress, the DC integration in energy systems (via smart grids and heating networks), as well as the structural transformations of the sector, especially with the development of hyperscale DC and the emergence of edge computing.

- Next, we analyse the dynamics and prospects for the development of DCs in Europe, based both on local case studies and on putting DCs into the context of what a net zero energy policy means for major electricity loads in Europe.

- The final part of the report is devoted to policy and regulatory recommendations so as to optimise the development of DCs in Europe, both in terms of the EU's digital and environmental ambitions, and in such a way as to optimise the economic effects associated with this development.

02

UNDERSTANDING DC ENERGY CONSUMPTION AND CARBON FOOTPRINT DYNAMICS

2 Understanding DC Energy Consumption and Carbon Footprint Dynamics

In this section, the objective is to distinguish DCs in the ICT ecosystem, explaining how they have managed to stabilise their energy consumption overall, as distinct from the ecosystem as a whole. The DC industry has seen significant efficiency gains with the rise of hyperscalers able to exploit higher utilisation rates and more efficient heating and cooling systems. It remains to be seen if that will be enough to prolong this performance over the coming decade, given the expected rise in consumption of ICT services caused, among others, by the health crisis. DC operators are increasingly using renewable energy power purchase agreements (PPAs) to cover their electricity energy needs. It is important to understand how these can facilitate the energy transition in Europe, given EU and national net zero energy targets.

Box 1: What is a DC?

A DC is a building or part of a building that hosts computer servers that run continuously. Servers perform computing, data storage and communication (network) functions that are the essence of the Internet. The specific features of DC come from the need to supply continuous service. To do so, they require cooling systems and heat exchangers, battery storage (UPS), diesel back-up generators, fire and other security systems and connection rooms.

DCs can be:

- enterprise level, often on-premises, dedicated and optimised for the use of one company, operated in-house or managed by a third-party;
- co-location, servicing several companies;
- edge – offering computing and storage closer to users, needed for IoT applications;
- hyperscale – large DCs offering a variety of services including cloud computing, access to virtual machines, big data storage and access to Software-as-a-Service (SaaS) platforms; and
- telecom – specialized in connectivity, delivering content to users.

According to their reliability, DCs are ranked by tiers, with Tier 4 being the one with the highest reliability thanks to built-in redundancy for every component, ensuring the greatest uptime.

2.1 Terms of the debate on the environmental footprint of ICT

2.1.1 Context: the tension between the contribution of ICTs to the fight against climate change and their own carbon footprint

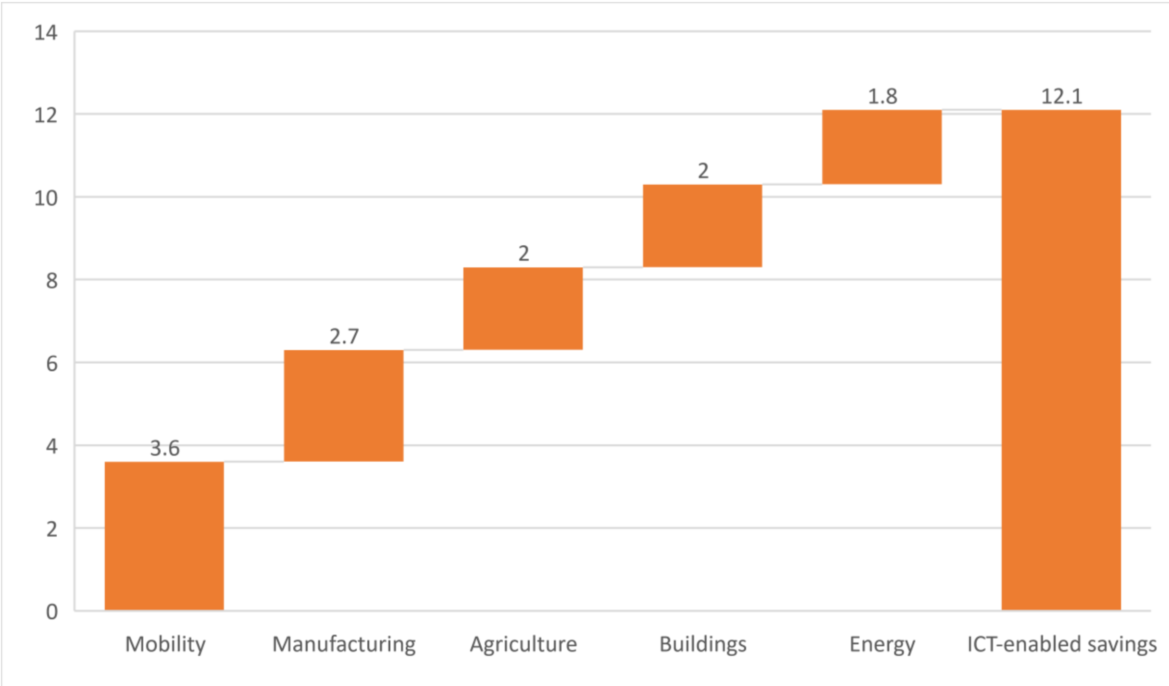
The economic implications of the Paris Agreement are staggering. From now on, the world needs to produce wealth while emitting considerably less carbon and ensuring universal access to modern forms of energy to a growing population. In very concrete terms, limiting the temperature increase to +1.5°C implies reducing emissions by a factor of six by 2050, hence returning to the levels of 1950 but with a tenfold increase in GDP and an almost fourfold increase in population. We discuss the implications of net zero by 2050 for European energy policy in general and hence DCs in particular in more detail in Section 4.5.

Changing the macroeconomic model in a decade is therefore a significant challenge. The required breakthrough is of such a magnitude that it cannot only involve the 'pure players' in the energy sector. Energy efficiency gains will be needed in all areas, and the massive deployment of new technologies and innovation will be crucial.

In this context, the rapid adoption of emerging ICT technologies and paradigms (i.e., IoT, cloud computing, AI, big data, data analytics, blockchain, 5G) contributes to the modernisation of our economy, from transport to manufacturing. During the COVID-19 crisis, information technologies also demonstrated their contribution to the resilience of our societies. These technologies will be at the heart of the economic recovery, with the prospect of accelerating the digital transition.

Moreover, they can also be one of the levers in the fight against climate change, with the potential to reduce emissions by up to 20% by 2030, according to some estimates, in a wide range of sectors and uses (GESI, 2015).

Figure 1: ICT CO_2 abatement potential (GTons, 2030)



Source: GeSI (2015).

However, it is essential to analyse the energy footprint of the long-term deployment of ICT, as this is a driver of growth in electricity consumption, alongside transport and air-conditioning. Although digital technologies represent an obvious asset in the face of the 21st century environmental challenges, they cannot escape the physical constraints that weigh on every sector of activity: availability of energy and mineral resources, biodiversity and the vulnerability of ecosystems, atmospheric pollution, etc. It is therefore essential that environmental gains induced by digital technology, such as remote work, smart cities and buildings, are not cancelled out by its impacts in terms of GHG emissions and use of abiotic resources and fresh water.

2.1.2 Dynamics of CO_2 emissions linked to ICT energy consumption

Available estimates put total ICT-related (including, but not limited to DCs) CO_2 emissions, at around 4% of global emissions in 2020 (Andrae and Edler, 2015; GeSI, 2019; GreenIT, 2019; Andrae, 2020a). This order of magnitude represents, to take a point of comparison, more than the 2% of global CO_2 emissions usually attributed to civil air transport.[11]

For 2030, Andrae (2020a) estimates that the sector's emissions are expected to increase slightly to around 5%, while Malmodin and Lunden (2018) show that ICT efficiency gains resulted in stability in terms of carbon footprint during the 2010 decade. If energy efficiency gains are exhausted and data traffic continues to grow strongly, higher percentages are possible. This is based on concerns that energy performance will be capped once all good practices have been applied.

Understanding what is likely to determine future ICT emissions induced by these technologies is essential:

- The carbon footprint of electricity supplying digital services, which depends on public decarbonisation policies of power systems, but also on the strategies of operators along The value chain, from upstream (equipment manufacturing) to downstream (delivery of the final service), via transmission networks;
- The pursuit of energy efficiency gains illustrated by 'Koomey's law'[12];
- The impact of the new uses already in progress (streaming video, online gaming, etc.) – or of new processes (AI, blockchain, those induced by the health crisis (remote working in particular) or that could be made possible by the new investment cycles (e.g., autonomous vehicles).[13]

All of these factors underline that, while the part relating to equipment (telecommunications networks, households equipment, etc.) can be considered as having a relatively homogenous carbon footprint, this is not the case for electricity sourcing. Therefore systemic performance will be extraordinarily heterogeneous from one country (or even one region) to another, which is of particular interest in Europe.

[11] According to estimates by the Air Transport Action Group, https://www.atag.org/facts-figures.html

[12] Koomey's law describes a long-term trend in the history of computer hardware. The number of calculations per joule of energy dissipated has doubled every 1.5 years, a trend that has been remarkably stable since the 1950s. (Koomey J.G et al., 2011),

[13] It should be noted, however, that while the overall evaluations give convergent orders of magnitude, those relating to specific uses can lead to very heterogeneous evaluations or even give rise to debate. By way of illustration, see the debate on the footprint of video streaming (Kamiya, 2019b).

Box 2: What impact will the roll-out of 5G networks have on electricity consumption?

The case of 5G illustrates the tension between the energy consumption of ICTs and their leverage effects in terms of efficiency gains in socio-economic activities. In 2018, the GSMA published a report explaining that each tonne of CO_2 emitted for mobile phone activities avoided the emission of 10 tonnes, for example by reducing transport activities (GMSA, 2019). 5G is designed to connect people, machines, objects and devices, thanks to its higher capacity, lower latency, improved reliability and greater number of supported connections. Smart use of resources will significantly reduce GHG emissions in a variety of ways, such as better support for energy management in cities and smart buildings, reduced office space and travel requirements, and efficient just-in-time supply chains through predictive analytics. In 5G, the traffic load on the networks will be considerably higher (due to the nature of the additional uses), but this new generation will be more efficient than 4G in terms of the amount of bits of information delivered for a given unit of energy consumption. A breakthrough brought about by 5G concerns the implementation of so-called "Massive Multiple-Input Multiple-Output" (Massive MIMO) antennas that transmit the signal only in the direction of the communicating mobile, rather than over a wide area as 4G antennas do. In addition, 5G generalises advance idle modes: this involves selectively switching off one or more devices in the absence of traffic (Lopez Perez et al.,2021). Because they have integrated the energy efficiency challenge from the outset, 5G technologies, once they reach maturity by 2025, could reduce energy consumption per gigabit transported by a factor of 10 compared with 4G, and by a factor of 20 by 2030.[14]

2.2 Key factors determining DC energy consumption

As the majority of Internet Protocol (IP) traffic is routed through DCs, they are an increasingly critical part of the development of digital services. Given its electro-intensive nature, requiring power supply and cooling, understanding DC activity is essential to understanding the global dynamics of ICT energy consumption. As a consequence, an important body of literature emerged in the 2010s to analyse the electricity demand of DCs and, in particular, the dynamics of their energy efficiency gains (Oró et al., 2015; Rong et al., 2016; Ni and Bai, 2016).

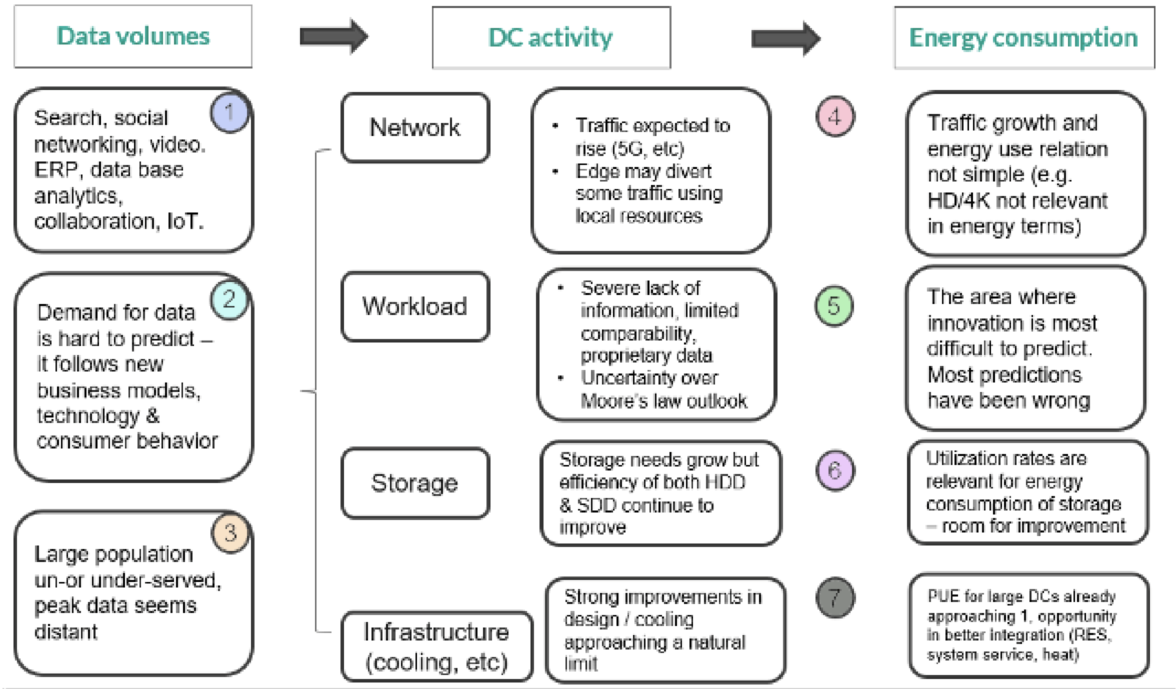
2.2.1 What drives energy consumption in DCs?

DC energy use can be divided into four segments: traffic, computation, storage and infrastructure (Koot and Wijnhoven, 2021). While the latter, including cooling, lighting, security, UPS in the form of battery storage and back-up power generators, is fairly straightforward to measure and forecast, the others have a complex relationship to energy use. More traffic, computation and storage do not necessarily translate into proportionally higher energy consumption. Moreover, since different types of data applications have different profiles of use in the three categories, comparability between DCs is limited. Hence, even measuring actual recorded consumption and understanding its evolution over time represents a challenge. Things get even more complicated when it comes to forecasts, as behaviours, use cases and technological improvements are hard to predict and can generate enormous differences in energy consumption, especially over longer periods of time. Even projections over shorter periods of time are difficult, as various counterintuitive evolutions have shown. For example, according to some accounts, 2020 has seen minimal growth in energy consumption despite the surge in data use associated with the pandemic (Masanet et al., 2020).

[14] According to a study presented by Orange, available at: https://hellofuture.orange.com/fr/la-5g-lefficacite-energetique-by-design/

Figure 2 offers a framework which draws out what might drive overall electricity demand from DCs. We discuss each of the boxes in the figure in turn below.

Figure 2: A visual representation of the relationship between demand for data, DC activity and energy consumption



Source: Adapted from Koot and Wijnhoven (2021) and Masanet et al. (2020)
ERP = Enterprise Resource Planning; PUE = Power Usage Effectiveness.

(1) The least controversial aspect regarding ICT's energy impact going forward is the increase in the demand for data which is accepted almost unanimously (Andrae, 2020 ; Masanet et al., 2020). The main established behaviours of today, accounting for almost all data use are internet search, social networks and media (especially video streaming) for individual users while for businesses they are ERP solutions linked to the cloud, analytics, databases and collaboration software (Koot and Wijnhoven, 2021).

The carbon footprint of different types of uses has become a prominent subject, yet estimates vary wildly, due to the difficulties of setting the accounting boundaries, the time versus data approach and limited access to information (Masanet et al., 2020). For example, a widely quoted exercise of estimating the climate impact of watching an hour of video (Netflix) is believed to have been overestimated by a factor of 90 (Kamiya, 2019a). The reasons include human error (mistaking bits for bytes) and using outdated electricity carbon intensities. While not entirely clear what activities will be the main drivers, growth in data demand is taken as given, especially as the number of smart devices increases due to their increased penetration across the global population.

Box 3: New drivers of data demand growth

VPN - An important data vector is the use of VPN (virtual private network) technology, which allows the users to encrypt the internet traffic and acts like a proxy for unlocking access to non-local content, such as teleworking (frequently used since the beginning of the pandemic), media content, etc. The encryption process and the connection to remote servers add operations in comparison with normal connections, increasing the traffic and computing, thus increasing DC activity.

Digital twin - A set of tools that is increasingly used in pre-construction and construction phases, but especially in operating phases for different assets (industrial facilities, factories, complex buildings) are based on the digital-twin technology, a virtual clone-representation of the asset, which digitally simulates the real-time subject throughout its lifecycle. To do so, these technologies require an increased number of sensors and increased communications with servers for continuous simulations. Thus, successful utilisation of a digital twin service – which needs to provide fast and accurate feedback to the asset's administrators – heavily relies on higher data traffic.

3D printing - A relatively small but expanding industry, 3D printing will be part of future manufacturing and building operations, as it ensures a highly efficient use of materials (virtually, no waste materials), low downtime, thus increased deployment times, operational expenditure (opex) reduction (UNECE, 2021). Decentralised production and manufacturing will require continuous updates and data traffic between the license owner's data server and the user's terminal. Therefore, data transfer is key to manufacturing and production processes, thus DCs' support is critical for ensuring a continuous 3D printing operation. At the same time, in theory, 3D printing technologies match the demand-side response services, as the operating speed can be adjusted based on the grid's demand which implicitly will also decrease the data traffic pressure.

Blockchain & Cryptocurrency - Blockchain technology and one of its main outputs, cryptocurrency, are often brought to the attention of both the authorities and the public, raising important questions about their high energy consumption – which generates (directly or indirectly) additional fossil fuel burning – and associated environmental externalities (Krause and Tolyamat, 2018; Truby, 2018). Blockchain is based on a decentralised technology, a peer-to-peer system, as a global network of computers is jointly managing the database of transactions. The main advantage is that there is no central authority to control, regulate and manage the data transfer. Additionally, as both data storage and processing are done individually and shared by network participants, the risk of the data being hacked is low.

Therefore, although the blockchain technology has a lower impact on large DCs, the trading of cryptocurrencies – as any other trading transactions – heavily depends on DCs. Nowadays, tens and hundreds of cryptocurrencies are launched every year, coins that are issued and traded through the high energy-intensive blockchain technology, practically a digital ledger of transactions. This has a particular impact on cities, as the processes put a high stress on the local utility network and pose environmental challenges, while their social and economic benefits for local communities are not so clear (de Vries, 2020). The high electricity demand has negative effects on the network congestion management or, more obvious to local end-consumers, on the grid's resilience issues such as power breaks. Additionally, social and economic concerns related to affordability have been elevated by consumers and regulators, as a higher energy demand will inevitably drive prices up. To this end, it is important, especially for local authorities to properly assess both the benefits and challenges brought by these technologies for different communities and their potential evolution.

2 Predicting what other sources of data use will emerge is also not simple, as innovation or adoption behaviours may follow non-linear trajectories. However, certain trends are visible. The rise in IoT and Machine-to-Machine communications has already started (Cisco, 2020), blockchain and its various applications, including cryptocurrencies, are projected to accelerated their growth, and the rise in the number of internet users is evident (Cisco, 2020). Teleworking, telemedicine, e-learning, online gaming, video streaming, virtual / augmented reality are all growing sharply. Some of the new uses that are already emerging or likely to take off are detailed in Box 3.

3 The unserved and underserved populations and regions are likely to catch up, further accelerating demand growth. The current differences in internet usage between Western Europe and Central and Eastern Europe are likely to be evened out by 2023 (Cisco, 2020). Furthermore, data traffic with MENA may also have an impact on EU DC activity. Currently, 83% of data traffic in the Middle East is routed through Europe (Equinix, 2021). As demand for video and media content continues to rise in the emerging economies of the region and the weather and electricity advantages of Europe will continue to fuel DC development, the overall effect on energy and emissions may become significant. However, this growth may reach a plateau at certain a point in time. While this point seems far away, it can be theoretically conceived that a sort of data saturation may occur, when data use will be constant or growing at the rate of economic growth. What the energy consumption will be when that point is reached is too complex to predict.

4 Traffic through data networks between users and DCs and between DCs themselves is an important component of the energy impact of DCs. DC IP traffic in 2018 was 10 times higher than in 2010 (Masanet et al., 2020) and growth is expected to continue at 22% CAGR (Cisco, 2019). Other estimates consider data to have gone up 30 times in 10 years by 2015 while computing capacity per unit of energy grew 100 times over the same period (Cisco, 2020). Rising mobile traffic and the new 5G standard will clearly have an important role to play. The emergence of Edge Computing (discussed below) may divert or prevent some traffic but that evolution is far from certain, as IoT itself is expected to generate far more data in the near future. On the other hand, the growth in data traffic does not have a simple relationship with energy consumption. For example, streaming a video in HD is said to have a negligible impact in energy terms, since the amount of time using the consumer equipment is more relevant than the flow of data (Kamiya, 2019a).

5 Computation is another function of DCs that has seen dramatic growth with 'compute instances' in 2018 five times more than in 2010. The improvement is following the time-honored Moore's law which estimated that the number of transistors per silicon chip (proxy for computing power) doubles every two years. While there are signs that this evolution is slowing down after years of tremendous progress (Waldrop, 2016), processor efficiency improvements are still expected (Masanet et al., 2020). In addition, better utilisation and reductions in idle consumption are also expected to continue thanks to virtualisation – the practice of pooling available resources and dynamic allocation to supply the current demand in order to optimise utilisation.

6 Storage needs have also gone up sharply, with social network activity and streaming the main drivers of demand. In 2018, the existing storage capacity was up by a factor of 25 compared to 2010 while its energy consumption had only tripled (Masanet et al., 2020). Thus, the energy consumption per unit of storage (terabyte) has improved dramatically owing to greater drive density and efficiency. The evolution of low-power storage is expected to continue to support this trend, meaning that storage capacity will be growing faster than energy consumption in the short run.

7 The infrastructure category groups together the cooling systems, the most energy intensive, but also lighting, UPS, security and others. The shift to hyperscale DCs that take advantage of economies of scale and are capable of implementing the most advanced technologies has meant that the energy efficiency overall has gone up significantly. The industry standard Power

Usage Effectiveness (PUE) measure – discussed below - is approaching its theoretical limit of 1, as the most relevant improvements in cooling techniques have been implemented. The continuing trend of shifting data needs towards hyperscales will mean more energy efficiency, but the region of diminishing returns has been reached and the limit is already visible. Further advances can come either through breakthrough innovation such as underwater DCs[15] or by further renewable energy deployment, system integration, flexibility services and heat recovery.

Many of the improvements in the ICT technologies relevant for DC energy consumption were hard to predict a few years ago. The continuous push for improvement is clear but the results are largely unknown beyond a few years' time. The energy-related performance may continue the recent trend via some major breakthroughs (such as quantum computing or others yet to be even imagined) or indeed the energy performance improvements may start to fade away. In the short run, according to Masanet et al. (2020), there is still room for improvement by further shifting to hyperscales, increased performance of computing, more virtualization and low-power storage. Beyond that horizon, predictions are very imprecise.

2.2.2 What is the current energy consumption of DCs?

As mentioned before, DC energy use can be divided into four main categories. The first three are related to IT work: networks – communication between users and between machines; computing – carried out by servers through microprocessors; and the storage of data in drives. The last category is infrastructure and it includes cooling, lighting, UPS and other energy consumption related to maintaining the DC in operation. Because of the limited data availability (some information being commercially sensitive), the multitude of actors, and the difficulty in setting up the boundaries of the system, estimates of electricity consumption of DCs vary.

For Masanet et al. (2020), in 2010, total global electricity consumption in DCs was 194 TWh while in 2018 it reached 205 TWh. At a time of staggering growth in demand for data, the energy impact has been surprisingly low at nearly 6% (Masanet, et at., 2020). This is mainly explained by the growth of the cloud and hyperscale DCs at the expense of onsite servers with much lower energy efficiency. The various forecasts on the evolution of energy consumption of DCs are wide apart, with some estimates for 2030 10 times higher than others (Koot and Wijnhoven, 2021). Even ignoring the demand side, the uncertainty regarding the technological evolutions is making DC energy consumption difficult to model.

The performance of the last decade has been unexpected. According to the IEA (2020b), there was a period of strong growth in electricity consumption in the 2000s. In the 2010s, DCs represented about 1% of global electricity consumption (c.200 TWh, as above). At the same time DC workload has increased eightfold over the period, while Internet traffic has increased by a factor of 12. Expressed as energy consumption by computing instance, the energy intensity has declined by 20% per year since 2010. The IEA also considers it plausible that such a performance will continue into the early 2020s, in particular through better systemic integration, while drawing attention to the problems linked to the geographical density of investments, leading to clusters that put pressure on local ecosystems (Kamiya and Kvarnstrom, 2019).

In the European Commission study (Montevecchi et al., 2020, p.34), the wide range of estimates is emphasised: "*it is currently impossible to speak of a reliable state of knowledge on the development and level of the energy demand of data centres worldwide. According to the studies considered, the annual energy demand of data centres worldwide in 2018 was between 200 and 800 TWh/year*".

[15] For example the one of Microsoft: https://news.microsoft.com/innovation-stories/project-natick-underwater-datacenter

Masanet et al. (2020) – in an analysis that has received much attention - considers that the lower end of the range is the most plausible, and that many studies have neglected the efficiency gains that led to stable energy consumption over the decade 2010. To explain this stability, the following factors are highlighted:

- power consumption per calculation of a volume server has dropped by a factor of four, due to improved processor efficiency and reduced standby power consumption;
- the number of watts per terabyte of storage installed has been reduced by an estimated nine times due to storage disk density and efficiency gains;
- growth in the number of servers has slowed considerably due to a five-fold increase in the average number of compute instances hosted per server (thanks to virtualisation); and
- the steady increase in DC energy effectiveness (i.e., PUE, the total amount of energy used by a DC divided by the energy used by its computing equipment).

Some studies question the ability to offset, over the long term, the growth in DC activity volumes by continuing the efficiency gains recorded during the 2010 decade which would, moreover, question the evolution of the carbon footprint.

Andrae (2020), extending Andrae and Edler (2015), considers on the one hand, that the level estimated by the IEA (2020b), 200 TWh, is probably an underestimation, with 300 TWh seeming more plausible.[16] On the other hand, the efficiency gains will no longer be sufficient to offset the dynamic demand for DC services, whose consumption could reach 800 TWh in 2030 (with a margin of error of ±200 TWh).

Conversely, Masanet et al. (2020) call for caution in simply extrapolating based on recorded trajectories of data demand and energy consumption, given the high level of uncertainty around efficiency potential, innovation and technology and the limited data availability. They argue that overestimation can result in misguided policy choices, such as excessive capacity reservation. Based on their considerations, a doubling of data within the next three to four years is feasible without major energy implications, thanks to advances in the efficiency of computing, networks, storage and infrastructure. In parallel, adequate policies can be designed to incentivise further efficiency gains, innovation, renewable energy use and system integration.

The wide range of estimates for global DC electricity demand illustrates the need for more transparency around the underlying data, on which current estimates are based.

2.3 Measuring DC energy efficiency

PUE is the most widely used indicator for the energy efficiency of DCs (see Box 4). While simple and useful at determining improvements in reducing consumption associated with cooling and lighting, PUE does have some shortcomings. First of all, conceptually, it does not measure the efficiency of the actual work performed by DCs – computing (Flynn, 2013) – but rather the effectiveness. Just because more energy goes into computing relative to cooling or other energy uses does not mean the computing itself is more efficient. A DC with a higher PUE but a lower amount of data processing done per unit of total DC energy used is not more energy efficient overall than one with a lower PUE but a higher amount of data processing per unit of total DC energy used. In addition, the comparability of PUE across DCs is limited, being influenced by many factors unrelated to efficiency such as climate, design, use of different resources (such as water) or size. Finally, PUE tends to be

[16] These 300 TWh correspond to 1.5 % of the world's electricity consumption and Andrae (2018) forecasts 3% for 2025.

measured at the level of an entire facility that may host other activities apart from pure DC computing, which makes it difficult to isolate efficiency gains to the DC itself. Measurement is seen as challenging due to lack of access to granular and frequent enough data (Brady et al., 2013).

Box 4: The metrics of energy efficiency in DCs

PUE - Power Usage Effectiveness is the most widely used indicator, aiming at measuring the extent to which the energy consumed by the DC is used for processing. It is equal to the ratio of Total Power to Total IT Equipment power. The best possible score is 1 meaning that the DC uses 100% of its energy consumption for IT work. In reality the scores are higher than 1.

DCiE – Data Centre Infrastructure Efficiency – this measure is simply the inverse of PUE.

CUE – Carbon Usage Effectiveness – like PUE it measures the ratio of Total Power to Total IT Equipment Power but then multiplies the result with the Carbon Emissions Factor (carbon emitted per unit of energy).

WUE – Water Usage Effectiveness – the calculation is similar to PUE but having water use at the numerator. Many DCs use water for cooling, the ratio of water use to Total IT Equipment Power measures the effectiveness of water use.

PPE – Power to Performance Effectiveness – created by Gartner, it measures « server performance per kilowatt », overcoming the paradox that a server may have lower usage but high power draw.

ERF - Energy Reuse Factor – measures the ratio of energy resulted from DC operations that is reused to Total Energy Used. Generally the excess energy is used as heat when there is demand in the vicinity of the DC.

EER – Energy Efficiency Ratio – calculated to reflect the efficiency of cooling processes. It is equal to the ratio between the cooling system output and the power consumption of the cooling system.

COP – Coefficient of Performance is equal to the ratio of the cooling output to the work expended and is used to measure the efficiency of heat pumps, including cooling systems.

DCeP - Data Centre Energy Productivity – the result of dividing the useful work produced to the energy consumed to produce that work. It estimates the efficiency of actual computing. Useful work can be measured as the number of tasks performed in the relevant period.

Looking at the other measures in Box 4, PUE, DCiE and CUE are all related to each other. ERF, EER, COP and WUE are partial indicators, whose individual level might interact with other measures. For example better use of water might improve WUE but require more power, worsening PUE. Only PPE and DCeP get at actual data energy productivity, with DCeP being the conceptually better measure, because it looks at the total DC energy consumption.

Measuring DC ‘useful work’ in terms of the amount of data processing done by a given DC is not straightforward, given that different DCs may be doing different types of ‘work’. However measuring the ‘real’ output of a DC in this way would be in line with economy wide energy efficiency measures which focus on total energy consumption per unit of real GDP.[17] We note that the recent Climate Neutral Data Centre Pact does not mention DCeP (or an equivalent measure of data processing 'work' per unit of energy) as a target measure for DC energy efficiency, but does mention PUE.[18] Annex 4 includes details on the origin of the metrics in Box 4, as well as on their utilisation in corporate reporting. This confirms that PUE is the only one of these measures generally in use across the sector.

2.3.1 DC integration in energy and power systems

The energy and carbon footprint of DCs is a function not only of technical progress relating to the equipment and their management, but also of their integration into energy systems (heat recovery) and power systems (demand response, system services). Taking into account and strengthening the energy and thermal production capacities of DCs is part of a systemic vision of land use planning, as well as the coordination of multi-vector networks.

DCs could be integrated at the crossroads of electrical, thermal and data networks, via optimisation techniques to exploit their energy flexibility (Koronen et al., 2020). In such a context, the DC is integrated with the energy grid of a smart city and acts as an independent energy player, contributing to meeting the energy goals and needs of the urban area where it operates by trading energy flexibility services on the market. In the future, DCs, which already integrate batteries for UPS, may use them to stabilise the grid when needed. The facilities could also help integrate renewable energy onto local networks. Through energy marketplaces, DCs can act as active energy players integrated into the smart grid, opening up new business models (at an emerging stage at the moment). By using the potential for demand response and heat recovery, the DC industry could facilitate the low carbon transition to renewable electricity by contributing to the integration of intermittent renewables and producing decarbonated heat rather than simply being an additional energy load (Koronen et al., 2020).

Naturally, integration opportunities will depend on factors related to the direct environment in which the DCs are located and, moreover, on energy choices concerning the energy mix. For example, waste heat utilisation is mainly an option for DCs that are close to district heating systems. In other words, neither of the options that will be mentioned below represents 'standards' accessible to all DCs.

2.3.2 DC heat recovery and possible uses

DCs produce a large amount of waste heat due to the high rate of heat dissipation in computer installations. The recoverable temperature depends on the technology used, from 30 to 90°C, depending on the use of air or water (and the possible combination with a heat pump, which consumes additional energy, to raise the temperature to a useable level).

There are many potential ways of using waste heat, the most common being the direct use for offices or residential buildings or, on a larger scale, to supply a district heating system, often found in Northern, Central and Eastern Europe. Other uses may include drying or heating in industrial processes and, at low temperatures, for greenhouses and aquaculture.

Examples of successful heat recovery through district heating can be found in Scandinavia (Huang et al., 2020). In Stockholm, a DC operated by Ericsson is supplying 80GWh of recovered heat, enough

[17] See for example: https://yearbook.enerdata.net/total-energy/world-energy-intensity-gdp-data.html
[18] See Climate Neutral Data Centre Pact, Self Regulatory Policy Proposal Policy Initiative (undated). https://www.climateneutraldatacentre.net/

to supply 20,000 homes and reduce CO_2 emissions by 4,800 tons per year. Also in Stockholm, a DC facility operated by internet provider Bahnhof is receiving payments from the heat supplier Stockholm Exergi that offers a significant premium in winter time. Similarly, in Finland, three of the DCs operated by Telecity Group, are supplying heat to a total of 5,000 homes, while in South Dublin, an AWS-operated DC is linked to a district heating development.[19] Other use cases for the recovered heat include warming a swimming pool in Switzerland and the offices and warehouses of a newspaper in Canada. We also discuss how Facebook's DC in Odense in Denmark provides district heating in detail below (see Box 11).

In this way, the DCs are part of a circular logic of energy saving by capturing waste heat for useful purposes thus contributing to the energy transition objectives defined in the local development plans, jointly planning the development of all energy-intensive infrastructures. However, since DCs are generally dependent on the prior existence of district heating systems and the willingness of local public authorities, this optimisation path is far from being generalisable.

2.3.3 Contribution to the need for flexibility through demand response

In an electrical system dominated by solar and wind power, a major challenge will be to develop a system with flexible load management as a feature. Load management strategies for DCs could have considerable potential in this respect, all the more so as the operators of these infrastructures are supporting the development of renewable energies. This perspective is moreover interesting as DCs are connected and automated, essential characteristics to contribute to the supply of flexibility through demand response.

This flexibility may be achieved by geographically optimising the load between networked DCs (Toosi et al., 2017; He and Shen, 2021). By implementing constraints in the algorithms, workloads and thus power demand can be shifted without negative impact on service quality. While much of a DC's workload is time sensitive, a significant part of it is "deferrable but deadline-oriented" (Paul et al.,2015). This implies there is a certain degree of load flexibility and given the large power consumption, DCs can be particularly suited for demand response. Several models of server provisioning, scheduling and migration have been proposed and others are constantly being explored in order to allow DCs to manage their load so as to maximise renewable power use (Le and Wright, 2014; Zakarya, 2018; Huang et. al, 2020). According to one example (Fridgen et al., 2021), under certain assumptions, an energy intensive DC added to an intermittent renewable energy plant contributes positively to its net present value (NPV) by optimizing the output of both given their operational characteristics. Currently, it is thought that conservative resource provisioning at rack, cluster and entire DC levels is resulting in significant underutilisation, which means there is room for large improvements (Paul et al., 2015). However, this also brings challenges in terms of performance degradation of equipment due to load-fluctuations that need to be balanced against the gains in renewable energy maximisation (Jin, 2016). Overall, however it is the case that cloud service DC owners may not be able to manage their data processing demands as flexibly as say a steel or cement factory, which can 'simply' ramp up and down final output solely in response to local energy price signals.

In addition to increasing the share of renewable energy use at DC level, thus reducing the carbon footprint, demand response may also reduce grid constraints, alleviating some of the stress caused by DC clustering.

The potential for demand-response will vary according to the characteristics of the DC under consideration, the nature of the work allocated to it, and the nature of the energy system in which it is inserted. Some estimates place the potential of demand response at comparable levels with large

[19] See: https://www.codema.ie/projects/local-projects/tallaght-district-heating-scheme#

scale battery storage systems, with proper market design interventions unlocking this potential via its incentive effects (Liu et al. 2014). Koronen (2018) also estimated that the theoretical maximum demand response potential of DCs could be considerable in Europe by 2030. However, the capacity of current DCs to do this may be limited by lack of appropriate electrical equipment.

While the potential for DCs to provide flexibility to the grid has been studied in theory, there would seem to be few examples of the provision of flexibility in practice. This is because although DCs do have a UPS (and perhaps also back-up generation), this is not designed to respond to the grid proactively but only to protect the DC's own equipment in the loss of power in-feed from the grid. Thus the potential for DCs to provide flexibility services exists but would require reconfiguration of existing equipment and/or new investment. We discuss this in section 2.3.4 below.

2.3.4 Mobilisation of back-up capacity

DCs are equipped with battery back-up power (in the form of a UPS) to ensure stability of the electricity delivered and to compensate for network power failures. These units have the capacity to power the DC for a limited period of time (1-5 minutes) while the critical back-up power generation is started. Traditionally they have consisted of lead-acid batteries, but now they usually involve lithium-ion batteries. They can be connected to an onsite generation source, traditionally a diesel generator, to bridge the power gap between loss of utility and loading up the back-up power source. Traditionally the UPS was designed to come on in the event of a loss of grid power in-feed and to stop discharging once grid power was restored (in the event of a local outage). The UPS was not designed for exporting power to the grid. They can be designed with higher or lower levels of back-up battery capacity.[20] Onsite generation, which can ensure that the DC can operate indefinitely off-grid, can also be sized to be smaller or larger than a base energy requirement, with larger offering more reliability and potential for export to the grid.[21]

The configuration of UPS can be varied in terms of its ability to synchronise with the alternating current (AC) input side and export power from the batteries via a bi-directional rectifier (see Alapera et al., 2018, 2019). The power electronics can be configured such that the UPS battery and/or onsite generator could independently supply the grid with power or supply all or part the DC load while the grid was itself stressed (but still technically available). Indeed the DC could earn additional revenue from participating in frequency response or capacity markets. This would require DCs to invest in a suitably configured UPS, storage, onsite generation, electrical infrastructure and energy management systems. This power system would need to be capable of responding to signals from the system operator. It would come with some risks/costs for the DC, particularly in terms of wear and tear on its power system equipment (see Arnone et al., 2017). The ability of the UPS and back-up generation to follow the grid condition would mean DCs could participate in frequency response and reserve capacity markets, thus actively facilitating the energy transition to higher intermittent renewables.

With additional investments, these UPS units may represent a potential for grid balancing (Shi et al., 2018). Fuel cell systems also appear promising (Ma et al., 2018). In the short term, there is an issue with diesel back-up generators which need to be replaced with lower carbon alternatives. Until such technology becomes reliable and can be scaled, considering DCs as grid assets needs to be weighed against the carbon emissions from diesel or gas back-up generators. Some DCs have switched to biofuel, while others are considering hydrogen fuel cells, geothermal or utility-scale lithium-ion batteries.[22]

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[20] See: https://www.allaboutcircuits.com/technical-articles/uninterruptible-power-supply-systems-in-critical-data-centers/
[21] See: https://www.criticalpowersupplies.co.uk/blog/Using-UPS-with-Generators
[22] See: https://datacenterfrontier.com/beyond-generators-data-centers-pursue-new-approaches-to-backup-energy/

Generally, it is considered that large DCs have by design significant initial redundancy to accommodate their specific operational needs (Alapera et al., 2018). DCs can project higher energy resources (e.g., greater sized grid connection capacity) than they actually consume, at least from the perspective of the system operator. This may be partly because in a DC cluster there may be speculative purchasing of land for alternative DC sites and associated requests for grid connection, not all of which may materialise. This may be because DCs have been traditionally sized for rapid future data growth and hence start at much lower than full electrical capacity utilisation. More accuracy in designing energy and connection needs as well as innovative flexibility practices can help alleviate some of the stress caused to grids in the areas that have seen high DC development and clusterisation. DC battery-powered UPS systems can be oversized and underutilised. Hence, they are believed to be suitable for supplying primary frequency regulation services to the TSO, thus contributing positively to grid management (Alapera et al., 2018). More communication with the grid company about likely trajectories of future electrical use might improve grid planning (and reduce DC grid costs).

Other future applications may include the use of energy storage to displace the peak load and fill the valley based on the time-varying price of electricity, which involves a dynamic battery management algorithm (He and Shen, 2021). More broadly, effectively combining the use of intermittent renewable energies and the workload of DCs is a challenge in terms of algorithms, especially since it is also a question of optimizing the price of the electricity consumed.

Finally, it should be pointed out that that the type of service described here is not limited to UPS systems, but could also include battery installations enabled through DC providers in key parts of the grid (not necessarily co-sited with the DC itself). This addition of flexibility can supplement the DC owner's procurement of clean energy via a PPA with a renewable generator[23].

Box 5: Exploiting DC energy flexibility

Potential benefits for grid/smart city:

- improving the local energy stability, avoiding critical points for the energy balance;
- managing peak shaving in the DSO network; providing a firm load diagram (load levelling);
- providing local balancing service systems like voltage regulation;
- contributing to reduced congestion or RES curtailment;
- having the possibility to buy energy at lower price;
- having the potential to meet the increasing energy demand; and
- satisfying the energy demand using green energy.

[23] It should be noted that experiments have been conducted to use used batteries from electric vehicles, which are not efficient enough for a mobility service, but which could provide services expected for data centres: www.automotiveworld.com/news-releases/nissan-eaton-equip-new-eco-designed-webaxys-data-center-first-deployment-energy-storage-solution-france/

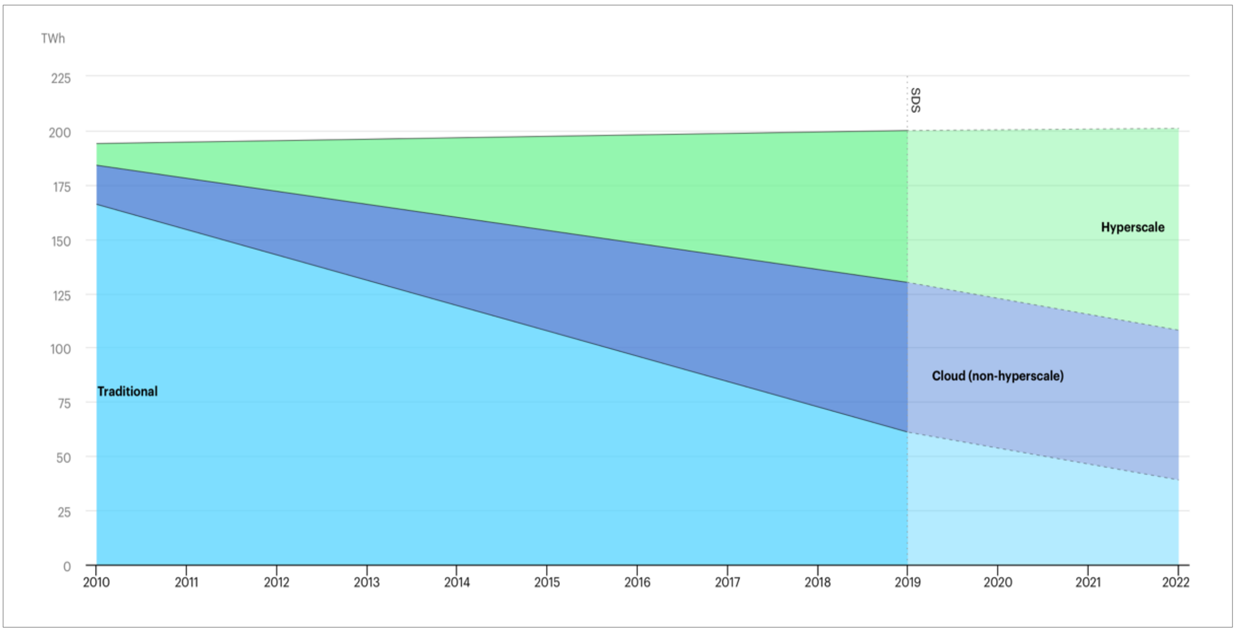
2.4 The structural transformations underway in the DC sector

This section is intended to explain the stability over time of DC energy consumption worldwide, in the context of the transformation of the sector and the massive deployment of hyperscale DCs, while stressing that, considering their size, the integration in local energy systems raises specific questions.

Part of the reason behind the stability of DC electricity consumption, despite the exponential growth of associated services, is the structural transformation in the sector with the emergence, as the dominant model, of large DCs known as "hyperscale". The short investment cycle lead to a shift from small installations of often energy-inefficient servers to more efficient, large-scale cloud-based DCs. This movement not only supports the demand dynamics of data storage and processing needs, but also a transition from on-premise to cloud-based centres, which is a factor in efficiency gains.

The idea behind building these huge centres for a single or multiple clients is to reduce costs and maximise reliability. From an energy efficiency point of view, hyperscale DCs have the advantage of being built for a single purpose and operated end-to-end by a single entity, allowing them to be optimised, unlike collocated DCs designed for multiple users.[24] This is partly due to virtualisation software that allows hyperscale operators to achieve higher throughput with fewer servers. In addition to this, hyperscale DCs are very energy efficient because they use proportionally much less energy for cooling, have higher utilisation rates, and typically use more modern and energy efficient server technology (AWS, 2019).

Figure 3: Global DC energy demand by DC type, 2010-2022



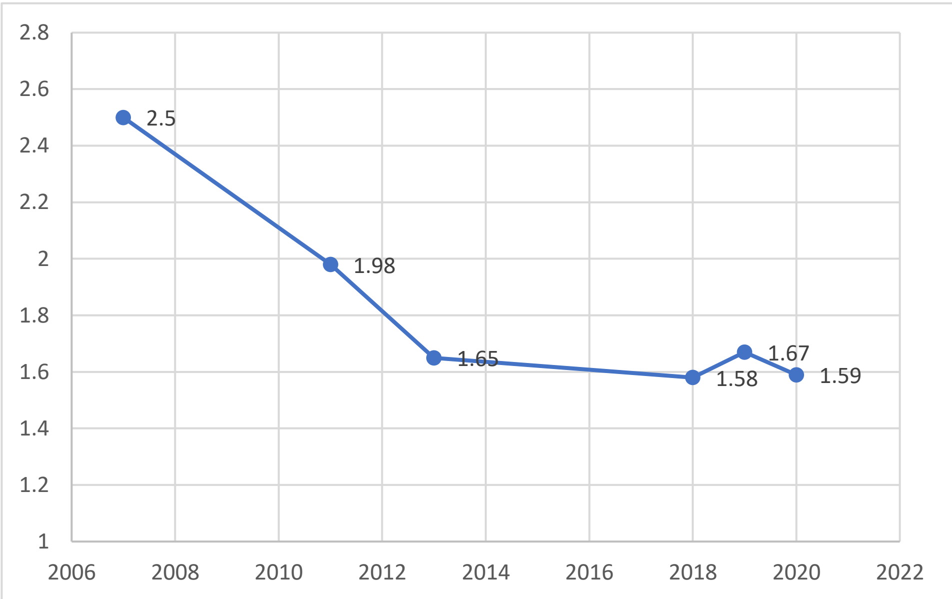
Source: IEA, 2020.
Legend: SDS: The IEA's Sustainable Development Scenario (SDS) outlines a major transformation of the global energy system, showing how the world can change course to deliver on the three main energy-related SDGs simultaneously: to achieve universal access to energy (SDG 7), to reduce the severe health impacts of air pollution (part of SDG 3) and to tackle climate change (SDG 13).

[24] From an energy efficiency point of view, co-location data centres are a little more problematic, as the data centre operator cannot control everything inside the centre, as customers can bring their own servers. In addition, co-location data centres are rarely used to full capacity, which naturally makes them less efficient.

Figure 3 shows a move to higher scale and cloud DCs, away from traditional enterprise DCs, although a large number of smaller scale DCs are still operating. According to Masanet et al. (2020), at the beginning of the 2010s, nearly 80% of computing instances were performed by small, traditional DCs, compared to 90% by larger, more energy-efficient (including hyperscale) DCs at the end of the decade. In order to grasp the transformation effect of this increasing predominance of hyperscale DCs, it should be noted that their PUE is now close to 1.1.-1.2 (the theoretical maximum being 1), whereas, by comparison, the efficiency of smaller DCs is both higher and somewhat stagnant since the middle of the decade, as shown in Figure 4. Better information is required however as it is difficult to assess progress with the weighted average PUE, at say the European level, as the shift to larger scale DC continues. For instance, comprehensive information on individual DC consumption (rather than voluntary survey-based information, on which Figure 4 is based) would allow better assessments to be made of the impact of data policy changes (e.g., moving data hosting to global cloud service companies) would have on overall energy use. It would allow better analysis of trends and their drivers.

This phenomenon can be observed in the following graph, which, based on a survey, shows the average efficiency per DC. Many small DCs, are sub-optimal and their performance may even have deteriorated due to the transfer of part of the processing flows to the hyperscales, as part of cloud migration.[25]

Figure 4: Average PUE of DCs



Source: Uptime Institute, 2020[26].

Legend: The Uptime Institute figures are based on surveys of global data centres ranging in size from 1 megawatt (MW) to over 60 MW, of varying ages. Note this is based on a survey asking IT and data centre managers for the PUE of their largest DC (i.e., the reported figure averages of the DC owners' largest DCs).

[25] Obviously, this average indication is not intended to reflect the overall performance of the data centre sector. Nevertheless, it does reveal that behind the emergence of large data centres, the entire fleet remains heterogeneous, and is still dominated in number by infrastructures that underperform compared to the best standards at the beginning of the decade. In reality, it is therefore rather the dispersion hidden behind this average that is likely to attract attention. "*As ever, the data does not tell a complete story. This data is based on the average PUE per site, regardless of size or age. Newer data centres, usually built by hyperscale or co-location companies, tend to be much more efficient, and larger. A growing amount of work is therefore done in larger, more efficient data centres (Uptime Institute data in 2019 shows data centres above 20 MW to have lower PUEs). Data released by Google shows almost exactly the same curve shape — but at much lower values*".

[26] See https://journal.uptimeinstitute.com/data-center-pues-flat-since-2013/

Thus, an essential part of the overall efficiency of the DC sector comes from the transition towards 'hyperscalisation', with the progressive marginalisation of small, under-performing DCs. However, as this process continues to advance, future gains may become marginally more difficult. As these DCs already have a very high energy efficiency in terms of infrastructure, the challenge becomes to supply them with decarbonised electricity, i.e., generally from renewable and intermittent sources, to help further improve their carbon footprint.

Consequently, due to their size, hyperscale DCs raise specific questions of integration in their direct environment, given their electro-intensive nature, while opening up opportunities for demand response, heat recovery and others. De facto, as we shall observe later in the European context, they are mechanically becoming structuring actors of local energy systems. Future developments in the nature of computing, such as Edge Computing, might impact the way data is processed the scale and utilisation of DCs (see Box 4).

Box 6: What effects can be expected from the development of edge computing?

Edge Computing (also called fog computing), in the context of the Cloud, implies processing data closer to its source or point of usage. Instead of indiscriminately transferring and processing data centrally in DCs, local resources are used in order to reduce latency and traffic (Gartner, 2018). Some applications include various forms of IoT objects like autonomous vehicles or surveillance cameras, video streaming or remote control, all of which require significant interaction and fast response.[27]

The idea is for computing that can be performed at the 'edge' of the network and use idle resources and thus avoid the costs involved with sending and processing data in large cloud DCs. Thus, Edge Computing is not meant to replace the Cloud, but to optimize its utilisation.

To some extent, Edge Computing is expected to reduce energy consumption (STL Partners, 2020). One way it could do so is by reducing unnecessary traffic, for example for video content. Data processing and storage nearer to the point of usage would mean less power consumed for sending data over long distances.

Another way could be through better resource utilisation (Jararweh, 2020). While centralised processing is more efficient at scale, in some situations, decentralisation can allow for more customisation. For example, some energy consuming components could be shut down when not used without affecting other processes, and thus use computing power more efficiently. In addition, less computing in the DC, could result in configurations that require less energy for cooling, other things being equal. There is also the possibility of AI applications deciding in real-time whether a process is to be run locally or centrally depending on various criteria, energy consumption being one of them.

However, in the European Commission study estimating DC consumption over the next decade, the scenario with a greater penetration of Edge Computing is considered to be the one with the second highest energy consumption – 120 TWh p.a. The reason has to do more with the assumption of building additional edge DCs to complement rather than substitute existing hyperscale DCs. Considering an increased number of IoT objects generating data and requiring Edge Computing facilities, the scenario of increased consumption is plausible. However, this should not be seen as a matter of efficiency but rather of increased volumes. As Edge Computing reduces unnecessary traffic, at equal volumes of data, it should be more energy

[27] See: https://www.accenture.com/us-en/blogs/cloud-computing/what-you-need-to-know-about-edge-computing

efficient. Thus, while Edge Computing may lead to more computing, the increase in energy consumption is not expected to be proportional.

In a way, Edge Computing may help at partially decoupling the growth in data processing from energy consumption by reducing traffic and optimizing computing power.

2.5 DCs in the ICT players' decarbonisation strategies

Insofar as major ICT corporations are the main actors in the dynamics of the hyperscale DC, it is essential to place these investments in perspective in their decarbonisation strategy and, in particular, in the logic of their investments in renewable energies.

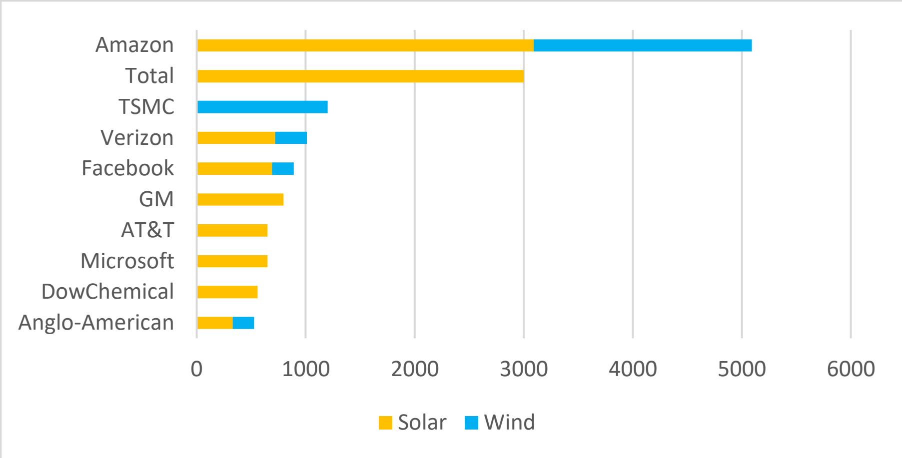
These firms are among the industrial players aiming at carbon neutrality in the short term. Amazon, Microsoft and Facebook have impressive corporate commitments to the achievement of net zero across at least their scope 1 (direct) and scope 2 (purchased energy) emissions. Amazon is committed to being net zero by 2040 and using 100% renewable energy by 2025, and they have established a $2bn climate fund.[28] Facebook committed to 100% renewable energy and being net zero across scope 1 and 2 emissions by 2020.[29] They aim to be net zero across their scope 3 (supply chain) emissions in 2030. Microsoft are aiming to be carbon negative by 2030 across scope 1, 2 and 3 emissions, 100% renewable energy by 2025 and remove their historical emissions by 2050. They have established a $1bn climate fund.[30] Although these DC owners are different in terms of products, services, value chains and decarbonisation challenges, they do have in common that they manage hyperscale DCs, with advanced efforts in energy efficiency and carbon free electricity sourcing.

For this reason, ICT players are major investors in renewable energies, often through corporate power purchase agreements (PPAs). A PPA is a contracting mechanism by which a renewable energy buyer makes a long term commitment to buy renewable energy from a project. This enables the project to secure financing. A PPA benefits the renewable energy developer in being able to add new renewable energy to the grid – often without relying on support schemes – and provides the buyer protection against volatile energy prices and reduces their impact on the environment. Corporate renewable purchasing is also a tool for companies such as Amazon, Facebook and Microsoft to reduce their carbon emissions. ICT companies operating large DCs dominate the global purchases of renewable energy in recent years (BNEF, 2020). To the extent that corporate PPAs lie outside government support schemes for renewables but still contribute to the achievement of government targets, they reduce government scheme support costs to other electricity consumers.

Corporate renewable energy purchasing via a PPA represents a key enabler of this objective, resulting in additional renewable energy capacity added to the grid. By setting a fixed power price for a pre-determined period of time, a PPA will also improve the predictability of a key cost element for a large electricity consumer with relatively high investment costs. PPAs are commonly accompanied by Guarantee of Origin (GO) certificates. A GO allows the electricity buyer to credibly claim ownership of a certain amount of renewable electricity (Copenhagen Economics, 2019).

[28] See: https://sustainability.aboutamazon.com
[29] See: https://sustainability.fb.com/wp-content/uploads/2020/12/FB_Net-Zero-Commitment.pdf
[30] See: https://blogs.microsoft.com/blog/2020/01/16/microsoft-will-be-carbon-negative-by-2030/

Figure 5: Corporate renewables procurement: Top corporate off-takers (MW, 2020)



Source: BNEF (2021)

Such mechanisms allow corporate renewable energy buyers to cover 100% of the electricity consumed by a DC via purchases of green electricity, without it necessarily being supplied 100% of the time. This highlights the point that corporate PPAs which cover 100% of the electricity purchases of DCs do not directly help with the management of the grid in real time. Corporate commitments to 100% renewable energy exist at different levels (e.g., the level of the single electricity market in Europe) and do not necessarily commit DCs owners to decarbonising the grid in an individual country or electricity market zone[31] PPAs are financial instruments used to purchase renewable energy while the grid management issues in real time require physical capacity to be available. The two are related in the sense that more corporate PPAs should increase overall renewable energy supply. However renewable intermittency and local grid congestion mean that even in the presence of PPAs, renewable supply and demand cannot necessarily be matched in real time, explaining why corporate commitments at the level of individual countries or electrical zones are difficult to make.

Another ambitious corporate clean energy goal, driven by Google, is aiming at supplying DCs with carbon-free electricity 24/7 (Google, 2020), and would cover all of its activities by 2030[32]. Google's goal is only conceivable because of the recent rapid progress and falling cost of solar, wind and storage. Achieving this goal will also depend on continued innovation in AI and machine learning to shift loads and increase efficiency for optimal energy use where and when renewable energy is predominant. The carbon-aware computing strategy implemented by Google will likely demonstrate the possibilities of delaying flexible workloads, using AI to predict the electricity mix and the day-ahead DC demand, impose hour-level limits while maintaining overall capacity.

Also noteworthy is Microsoft's initiative to enable its customers to obtain greater transparency on their total carbon emissions via a 'sustainability calculator'. This calculator enables cloud customers to monitor the total carbon emissions resulting from their use of the cloud. Using AI and advanced analytics, Microsoft's Sustainability Calculator provides practical advice on how to reduce emissions, increases the ability to predict emissions and simplifies carbon reporting. Such sustainability calculators with agreed standards for the industry could further facilitate trust and comparability.

[31] See for example: https://sustainability.aboutamazon.com/renewable-energy-methodology.pdf
[32] By comparison, in 2019, only 61% of all electricity used by the company was supplied by regional carbon-free sources on an hourly basis.

Microsoft also announced (in November 2020) an initiative to match their hyperscale DC demand in Sweden with renewable energy in real time via a contract with Vattenfall.[33] The firm also recently announced (in July 2021) a commitment to matching 100% of its electricity, 100% of the time with zero carbon electricity contracts, implying real time contractual matching of its power purchases.[34]

2.6 What might COVID-19 change as we progress through the 2020s: towards which 'new normal'?

- As a result of the pandemic, ICT use has grown strongly. While the extent to which these effects will endure past the health crisis is unknown, they may turn out to be structural, with the development, in particular, of remote working, as well as other services such as education or medicine.
- For example, about one-fifth of all jobs in the world could potentially be organised at home, from around 13% in India to over 45% in European countries (ILO, 2020). In addition, this period will have favoured the online consumption of media, leisure or cultural services, while at the same time weakening the companies or organisations that offer these same services face-to-face, with undoubtedly lasting effects beyond the pandemic.

The pandemic response precipitated significant changes in human mobility and greatly increased remote working practices that may endure in the longer term. Traffic that was normally distributed among enterprise, education, and public WiFi networks has been mostly redirected to fixed consumer broadband networks. Mobile networks have also seen faster traffic growth in some countries. This has caused significant changes in traffic composition, and introduced new challenges for networks worldwide (Sandvine, 2020). As a result, for the year 2020 as a whole, total spending on infrastructure services in the cloud increased by 33%, from US$107 billion in 2019 to US$142 billion (Canalys, 2020).

On the other hand, according to some accounts, the energy effect of the pandemic has been surprisingly muted, at least at some levels of the ICT system. For example, the network operators Telefonica and Cogent reported a significant rise in data demand but an insignificant increase or even decrease in energy consumption in 2020 compared to 2019 (Masanet et al., 2020). This proves that the implications of the surge in the demand for data and the potentially structural changes brought by the pandemic in this regard are still largely unknown.

Taken together, these factors undoubtedly render the Internet traffic growth scenarios for the 2030 decade obsolete, with a likely effect on the DC sector. It will therefore be important, both in the strategy of industrial players and in the related public policies to take this 'new normal' into account when analysing the objectives and conditions of decarbonisation of ICT services in general and of DCs in particular.

In other words, in an environment where financial constraints should not diminish climate ambitions, it will be no less essential to monitor the energy and environmental footprint of information technologies, but also to measure their contribution to the sustainable development of our societies, from an ecosystemic perspective. These challenges relate both to the management of GHG

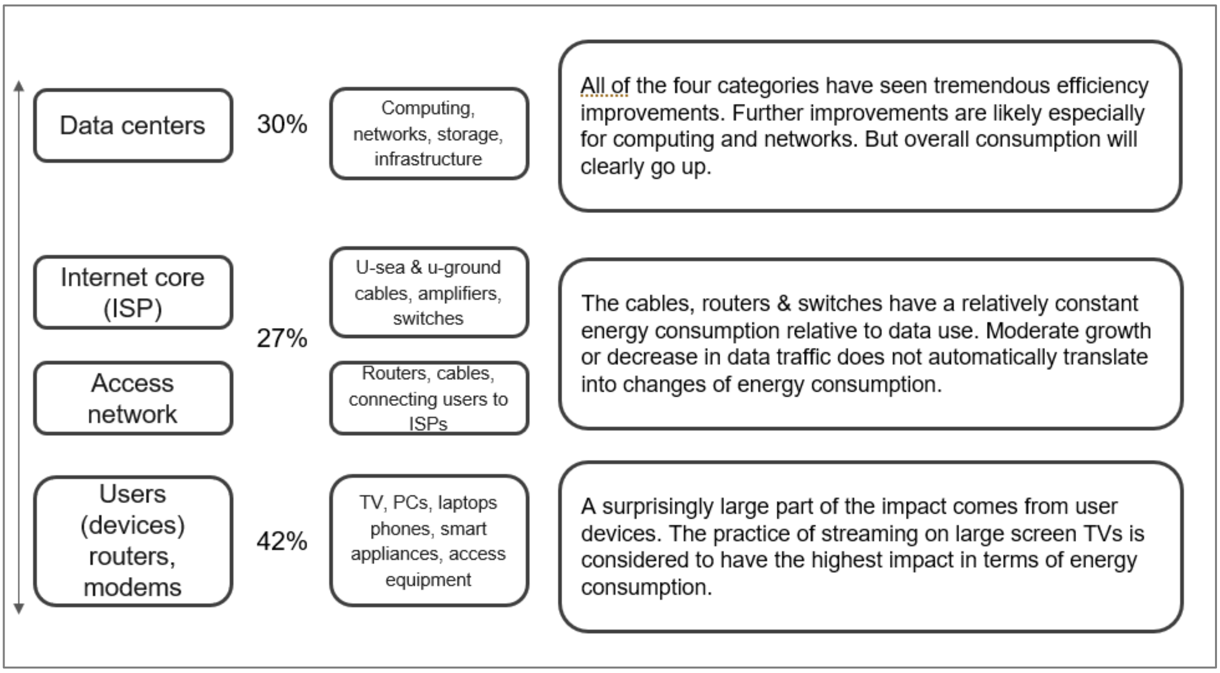
[33] See: https://azure.microsoft.com/en-gb/blog/achieving-100-percent-renewable-energy-with-247-monitoring-in-microsoft-sweden/
[34] See: https://blogs.microsoft.com/blog/2021/07/14/made-to-measure-sustainability-commitment-progress-and-updates/

emissions, of course, but also to a whole range of negative externalities such as air pollution, whose negative effects lead to an even higher mortality rate than COVID-19.[35]

2.7 DCs in the context of overall ICT demand

In discussing energy consumption in DCs, it is important to put them in their industry context. While the focus of this discussion is on DC energy consumption, it is important to acknowledge that DC electricity consumption is significant within the overall contribution of the internet to electricity consumption, but it is not the majority of internet-related consumption. At the moment, DCs are estimated to constitute 30% of overall internet demand, as shown in Figure 6. Thus network electricity consumption and user device consumption are also very significant. Energy efficiency improvements in these areas will also have a big impact on overall electricity consumption.

Figure 6: Electricity intensity of the Internet



Source: Adapted from Aslan et al.(2018) and Malmodin and Lunden (2018).

2.7.1 Positive and negative climate consequences of ICT growth

Accurately measuring the impact of ICT and implicitly DC activity in terms of sustainability and GHG emissions is definitely too complex given the data available but also the complicated interaction effects. However, existing research does point towards some interesting impacts of ICT that are worth mentioning (Coroama and Mattern, 2019; Lange et al., 2020).

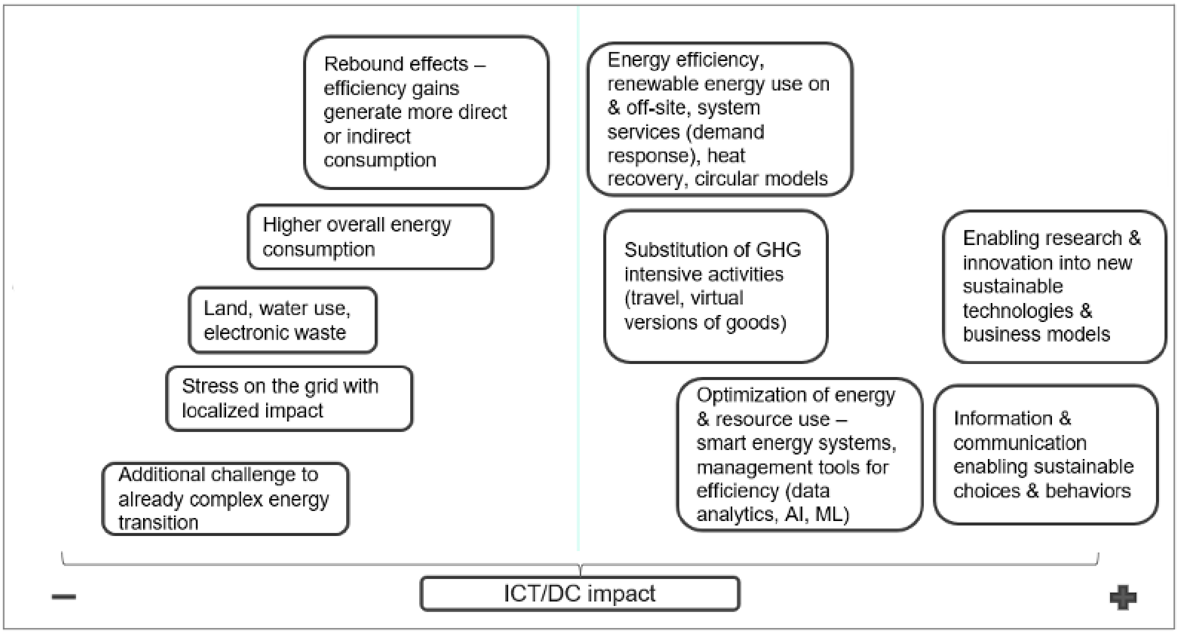
On the negative side, increased demand for data and DC activity results in higher energy consumption, local level impacts in terms of increased stress on the grid, land and water use and waste. Moreover, increased load from DCs is adding to an already complicated energy transition in the countries in which they are concentrated, where other existing sectors are trying to decarbonise at the same time, creating significant societal costs. This set of impacts is being mitigated thanks to all the DC-level evolutions mentioned above, increased energy efficiency both in IT work and

[35] Although the direct operation of data centres does not have a significant effect on air pollution, this may be the case, indirectly, depending on the quality of electricity sourcing: in countries where the electricity system still relies significantly on coal, consumption that is not covered by PPA powered by renewable energy is in fact contributing to air pollution.

infrastructure, the shift to hyperscale, renewable energy procurement, DC local system integration through demand response or heat recovery. In addition, the value added, jobs and other positive economic externalities of DCs are also relevant. Host countries are enthusiastic about attracting DCs for non-energy reasons such as economic development, job creation and low latency services for other businesses.

The next figure summarises the relative impact of ICT growth:

Figure 7: GHG impact balance of ICT



Another, perhaps more subtle impact is related to ICT impact on consumer behaviours and business decisions. The documented substitution effects – such as video conferencing instead of travelling, virtual goods replacing physical objects – may seem to directly reduce GHG emissions. The same can be said about optimising effects, with data allowing businesses to improve decision making and thus increase resource efficiency and energy productivity (Yan, 2018). Examples can be taken from virtually any business sector that uses data management tools to optimise processes. An even clearer positive impact comes from the feasibility of smart energy systems that can tackle the intermittency issue of renewable energy in ways that would simply not be possible without the advances in ICT. Other benefits will undoubtedly come from the emerging AI and IoT applications like vehicle fleet and traffic management, heating, ventilation, lighting and others[36] (6GWorld, 2021).

However, partly counterbalancing these positive impacts are the possible rebound effects, some of which have been documented, but whose overall impact is hard to quantify, though attempts have been made (Falch, 2012, GeSi, 2015). The rebound effect refers to this situation when the greater availability and affordability of a good leads to increased consumption of that or other goods. In the data case, the effect is intuitive. The more efficient and affordable data becomes, the more of it is being consumed, at least until a level of saturation is reached. This would be the direct rebound effect. In addition, more data use may enable the substitution of some activities with others or some choices and behaviours with an uncertain impact in terms of GHG emissions. One study has shown that remote working, under certain conditions, substitutes commuting with other travel (Cerqueira

[36] See: https://www.6gworld.com/sustainability-in-new-and-emerging-technologies

et al., 2020). ICT enables teleworking, saves on commuter work travel but these energy benefits need to be considered against rebound effects that impact total distance travelled and consequently GHG emissions. The rebound effects are also conceivable in businesses and industry. While data helps reduce resource use and cost, it makes more resources available for other activities that may or may not contribute to greater GHG emissions.

Coroamă and Mattern (2019) give the example of autonomous vehicles. They would not be possible without the ICT evolutions and will definitely be very data intensive. At first sight, their GHG impact is overwhelmingly positive as it allows for optimisation of fuel by reducing average speed, congestion, and distances between cars to limit wind resistance. The rebound from this will come from the greater attractiveness of using autonomous vehicles. New categories of users will emerge – the ones without the ability or appropriate age to drive, empty return or idle runs will become a possibility, thus countervailing the positive impacts.

Finally, another category of overwhelmingly positive impacts come from the seamless dissemination of information (and disinformation) that can persuade and enable people to take sustainable decisions. ICT is also helping research efforts that would not be conceivable in the absence of the data revolution, which may end up generating technologies that can mitigate or solve the climate crisis altogether.

03

QUALIFICATION OF THE ROLE OF DCS IN THE ENERGY SYSTEM UNDER EU LAW

3 Qualification of the Role of DCs in the Energy System under EU Law

This section aims to, first, legally define DCs under EU energy legislation (3.1) and, second, describe the role of the different actors in DCs' development in relation to the energy system (e.g., owner, operator, user) (3.2). This is important to anticipate the respective obligations for those different actors as well as their current and potential position on the energy market in Europe.

3.1 Qualification of DCs under EU legislation

3.1.1 Definition of DCs

DCs (see Box 1) refer to companies that have storage and/or processing of data as their main business activity. It is common to describe DCs as being formed of three groups of systems: ICT equipment, electrical and mechanical equipment, and a building infrastructure. The server room may share power and cooling capabilities with the rest of the building.

The JRC has proposed the following working definition for DCs as a product group:

> *"Data centres means structures, 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."* (JRC, 2020, p. 6)

Some common definitions have been elaborated, based on the EU Code of Conduct (European Commission, 2020e) and NACE.[37] Certain classifications also group together DCs and server rooms, referring then to definitions used by ASHRAE,[38] Best Environmental Management Practice (JRC, 2016, and Shehabi et al., 2016) on server rooms because they can form the same product group (JRC, 2020, p. 5).

Harmonising the definition of DCs is important for the regulation of the latter. It enables the identification of responsible entities, the definition of the scope and types of activities performed by DCs, the types of services provided, and enables the application of standards and rules. Harmonising some key definitions applicable to DCs also ensures a level playing field for the efficient development of DCs throughout the EU.

However, as of today, there is no common definition of DCs in EU legislation, which otherwise increasingly refers to the role of DCs. The Ecodesign Directive does refer to some products within DCs (e.g., air conditioning units), which can serve a usefull legal basis for developing a more comprehensive definition of DCs into EU law (see Section 5.3.2 below). Looking ahead at possible legislative amendments, proposals for revision of the Energy Efficiency Directive as part of the "Fit for 55 package" address the definition of DCs, which could answer this shortcoming (see Section 5.3.3 below). Likewise, the proposal for a new Directive repealing the current Network and Information Systems (NIS) Directive (EU) 2016/1148 (to be replaced by a NIS 2 Directive) includes the following draft definition of 'data centre service' (European Commission, 2020f):

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[37] Nomenclature Générale des Activités Économiques dans les Communautés Européennes

[38] BSR/ASHRAE Standard 90.4P. 3rd ISC Public Review Draft Energy Standard for Data centres. Third ISC Public Review (January 2016).

" '*data centre service' means a service that encompasses structures, or groups of structures, dedicated to the centralised accommodation, interconnection and operation of information technology and network equipment providing data storage, processing and transport services together with all the facilities and infrastructures for power distribution and environmental control.*"

Those proposals are seen as improvements that must be consolidated and coordinated across the different legislative acts.

3.1.2 Typology of DCs

There is a large variety of DC definitions and categorisation. The existing typologies often distinguish them based on size, ownership of equipment and infrastructure and IT load. The age of installation could also be taken into account to distinguish between old and new DCs, particularly for the purpose of reflecting the energy efficiency rate of the installations. Finally, one could also distinguish DCs based on the type of data processed. Taking this into account could notably enable prioritising certain DCs providing essential services for society. Such qualification could entail eligibility for exemption from certain obligations, or to preferential treatment, e.g., for grid connection rights, connection terms and grid tariffs.

The following four main categories of DCs are commonly identified:

1. **On premises DCs**: These are the most common type of DCs, mostly serving one customer and located within the premises of the company using the center for its own business.

2. **Co-location DCs**: A co-location DC is "a data centre facility in which multiple customers locate their own network(s), servers and storage equipment."39 Co-location DCs are often developed by actors having such facilities as main core business, e.g., a site developer, and offering the following services: robust power supply including back-up capacity; robust cooling capacity; connectivity; safety, fire, crime, surveillance (Energy Norway, 2016). The co-location centres usually have an organic growth and are developed step by step. Their size commonly varies between 1 and 10 MW.

3. **Enterprise DCs or data centre enterprises (DCE)**: A DCE is a DC which "has the sole purpose of the delivery and management of services to its employees and customers and that is operated by an enterprise."40

4. **Hyperscale DCs**: Large scale DCs are designed for improved efficiency, built and operated by specialized companies that offer services to a variety of customers.

3.1.3 Qualification of DCs among energy installations

Because DCs deliver strategic, essential services in a digitalised economy, it is worth assessing whether they could be defined as 'critical infrastructures' under EU legislation, and assess the pros and cons of such qualification. Critical infrastructure means any system which is essential for providing vital economic and social functions, such as: health, food, security, transport, energy, information systems or financial services.

In its European Programme for Critical Infrastructure Protection (EPCIP) of 12 December 2006, the European Commission set out an overall policy approach and framework for critical infrastructure protection (CIP) activities in the EU against all hazards and in all sectors. The four main focus areas

[39] Definition used in EN 50600-1:2012.
[40] Definition used in EN 50600-1:2012.

of EPCIP were: a procedure to identify and designate European critical infrastructures and assess the need to improve their protection, and regulated in the European Critical Infrastructure Directive (ECI Directive 2008/114/EC); measures to facilitate the implementation of the EPCIP, including expert groups at EU level, an information-sharing process and a Critical Infrastructure Warning Information Network (CIWIN); research on and subsidies for CIP-related measures and projects; and a framework for the cooperation with third countries.

Pursuant to the ECI Directive Articles 2 and 3, a European critical infrastructure (ECI) means an asset, system or part thereof located on EU territory, which is essential for the maintenance of vital societal functions, health, safety, security, economic or wellbeing of people, and the disruption or destruction of which would have a significant impact on at least two Member States (pan-European infrastructure), as result of the failure to maintain those functions. The significance of the impact is assessed against distinct cross-cutting criteria, which encompass casualties, economic and environmental effects and public effects.

The directive divides the ECI process into three stages, which are: 1) identification of potential ECIs (in principle derived from existing national critical infrastructures); 2) designation of ECIs (in agreement with other Member States affected); and 3) protection.

The scope of the directive is limited to two sectors, namely energy and transport, although it excludes nuclear energy, which is covered by other legislative instruments. Annex I provides a comprehensive list of eight subsectors, three pertaining to energy and five to transport. In the electricity subsection of the energy sector, infrastructures and facilities for generation and transmission of electricity with respect to supplying electricity are considered critical infrastructures. Since the scope is limited to energy infrastructures, DCs are not explicitly covered by the current definition, but they could be encompassed by the definition if directly related to the electricity critical asset/infrastructure.

However, a possible qualification of DCs as critical infrastructures is not necessarily the preferred regulatory approach. This would have important practical consequences for both DC owners and operators and for grid operators, which may not fit with the aim pursued. On the one hand, applying the regime of the ECI Directive to DCs would enable them to benefit from protection requirements set on ECI operators and competent Member State authorities. But on the other hand, it raises a series of practical and legal challenges related primarily to: 1) the definition of objective criteria for distinguishing between DCs, based on e.g., the type of industry they supply, or whether they process critical data or not; and 2) the potential supply protection DCs could benefit from during system stress. This comes in addition to more common issues related to e.g., regime for access to the grid or grid reinforcement.

From an electrical point of view, making all DCs equivalent to, say, hospitals, would have implications for both the grid and the DC owner. It would, in regions with significant DC demand, make the management of the grid much more difficult as increasing the priority load significantly makes the management of system stress events more difficult. For DC owners it could also have significant cost implications as they would be under increased scrutiny as to their ability to respond to system stress events. Hospitals typically have back-up generators which allow them to operate in 'island mode' for prolonged periods and this is subject to national regulation.[41]

Important legislative processes are ongoing with direct consequences for the classification of DCs as critical infrastructures or entities. It should also be noted that several countries, such as Australia, are in the process of enshrining into law the status of DCs as critical infrastructures. On 16 December 2020, the European Commission presented a new proposal for a directive on the resilience of critical

[41] See for instance: https://electricalreview.co.uk/2019/09/03/the-critical-condition-of-hospital-power/

entities (European Commission, 2020c). The proposal draws from the findings of 2019 evaluation of the Directive (European Commission, 2019b) and the calls made by the European Parliament and the Council to better align the ECI Directive with the Network and Information Systems (NIS) Directive (EU) 2016/1148 (and upcoming NIS 2 Directive). This is an opportunity to further refine the scope of application of the definition of 'critical entities' and bring further clarification on the potential inclusion or exclusion of DCs. Notably, the scope of the application of the NIS Directive is proposed to be extended to, for example, digital infrastructure (European Commission, 2020f). The proposal for a Directive relies on the definition of 'critical entities' and 'essential service' provided by these entities. As noted above, the proposal also includes a definition for 'data centre services'.

3.2 DCs' multiple roles in the energy system and interaction with other actors

The previous sections of this report have elaborated on the different roles that DCs can play in a more integrated energy system. For the purpose of advancing concrete recommendations in terms of policy and regulatory improvements, the roles that DCs are taking in the energy system can be summarised as follows:

- **Large energy user** – Typically in Europe 1MW+ peak demand would classify a load as a large user. Cloud DCs are typically well above this.
- **Grid users** - In most circumstances, large DCs will be connected to the high voltage grid and, less often, to the distribution grid. DCs often use double connections points to secure electricity supply.
- **Electricity and/or heat producer** – This will be the case for heat (waste heat), but also electricity if the installations include e.g., solar panel or onsite wind farms. If the produced electricity is used by the DC, the status of prosumers will apply. Surplus electricity or heat could also be fed into the grid and sold. Surplus electricity could also be stored onsite.
- **Local grid operator** – Depending on the location, the DC may need to operate a local grid.
- **Supplier of flexibility** -The DCs could also become providers of new flexibility products in relation to demand response.

04

EUROPE’S ATTRACTIVENESS FOR DC INVESTMENTS IN LIGHT OF THE CARBON NEUTRALITY COMMITTMENT

4 Europe's Attractiveness for DC Investments in Light of the Carbon Neutrality Commitment

In line with the objectives of the Green Deal, the European Commission set 2020 the following ambition in 2020: "*to achieve climate-neutral, highly energy-efficient and sustainable data centres by no later than 2030 and transparency measures for telecoms operators on their environmental footprint*" (European Commission, 2020a).[42] This ambition also echoes EU concerns about the transformation of energy-intensive industries, knowing that the DC sector will stand out for the strongest growth in capacity during the decade (European Commission, 2019c). Part of the DC industry has already aligned itself with the European Commission's objective by committing, in 2021, to a carbon neutrality pact for 2030.[43]

This proactive commitment will not solve all the problems associated with the deployment of DC capacities in Europe. For example, in 2019, Amsterdam established a one-year moratorium on new DC projects, given the density of these facilities in the urban area of the Dutch metropolis. In view of the strong growth observed, 10 to 15% per year over the last seven years, the local public authorities wanted a pause in order to assess and improve the rules in terms of access to space and energy. This situation observed in the Netherlands merits attention, as it is likely to foreshadow other 'congestion' phenomena in northern Europe, where a predominant part of investments has been concentrated, mostly due to colder climates being more conducive to managing heat dissipation in DCs (see Box 5).

The aim of this section is to better understand how increases in DC capacity and renewable energy resources in Europe can be organised in synergy and whether other parts of the EU are likely to host higher investment in the future, as a better geographical balance is likely to be a determining factor for effective future deployment.

In this section we discuss: the general DC landscape in Europe; some of the specific features attracting DCs to particular cities; detailed case studies on DCs in Ireland and Denmark; the implications of net zero for DCs, and conclude with some thoughts about future prospects.

4.1 The European DC landscape

4.1.1 Is Europe a DC-intensive economic area?

The information available on the DC industry is not granular enough to provide an accurate picture of the nature and location of the equipment, in particular because some of it is on-premises. The visibility concerning hyperscale is, however, better and, according to Cisco (2019), almost all hyperscale DCs are located in three regions: North America (46%), Asia Pacific (30%) and Western Europe (19%). These observations are corroborated by data from Synergy Research Group (2021), also focusing on hyperscale DCs, which underlines the predominance of centres located in the United States. These elements of comparison make it possible to notice that, at this stage, Europe is still not very dense in hyperscale centres compared to the United States, whose GDP is similar.

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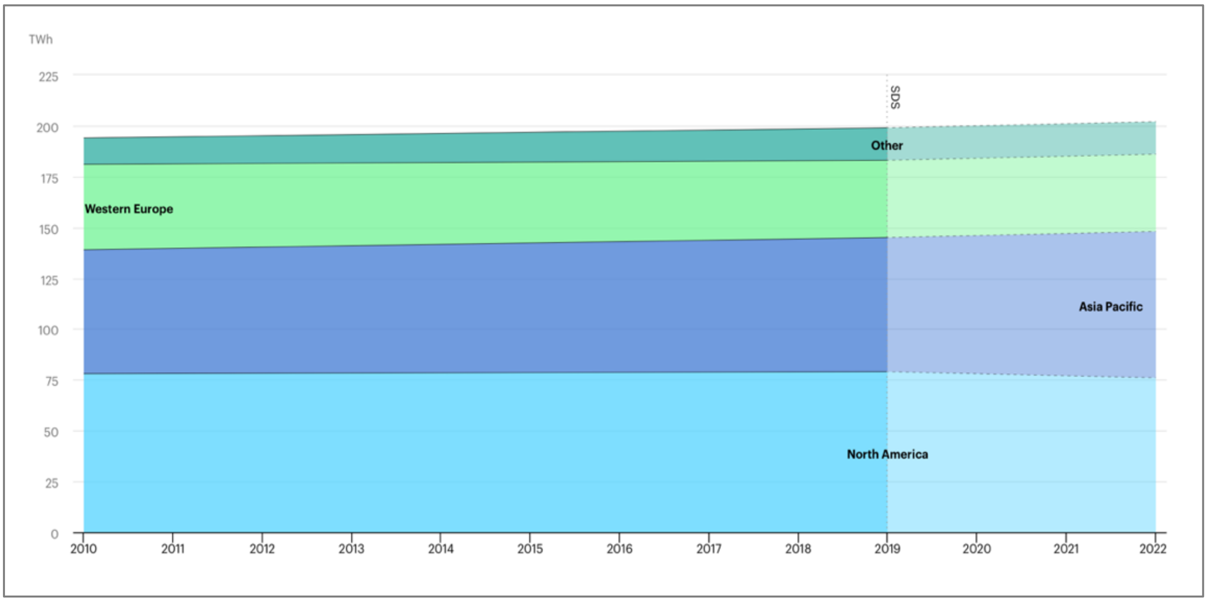
[42] This communication also provides for: *"A circular electronics initiative, mobilising existing and new instruments in line with the policy framework for sustainable products of the forthcoming circular economy action plan, to ensure that devices are designed for durability, maintenance, dismantling, reuse and recycling and including a right to repair or upgrade to extend the lifecycle of electronic devices and to avoid premature obsolescence."*
[43] See: www.climateneutraldatacentre.net

The reduced density in relative terms in Europe is confirmed by data on electricity consumption (IEA, 2020b). This leads to the perception that the concentration in certain regions of the EU probably raises more questions than its overall footprint in Europe at the end of the 2010 decade.

Figure 8: Global DC energy demand by region



Source: IEA, 2020

4.1.2 What are the dynamics of change at work?

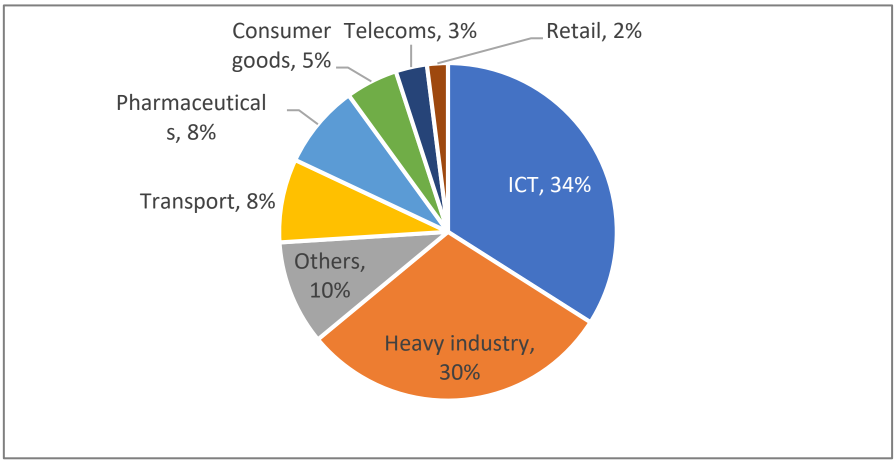
According to data from Synergy Research Group (2021) since the beginning of 2017, the European cloud market has more than tripled. This analysis is extended by various studies which predict both a 50% increase in the number of new DCs between 2021 and 2022 compared to 2019-2020 and a 50% growth in DC revenue between 2021 and 2025 (Research and Markets, 2021).

This rise is confirmed by the latest Emerging Trends in Real Estate Europe survey (PwC-Urban Land Institute, 2020), where DCs were among the top 10 sectors in which to invest, after logistics facilities and residential asset classes with strong growth forecasts over the next five years. Further evidence of this trend comes from the entry into the DC market of non-specialist institutions including real estate investment companies (Schroder European REIT), investment managers (Catella APAM), institutional investors (AXA), sovereign wealth funds (GIC, PFA) and infrastructure funds (Brookfield Infrastructure Partners, EQT Infrastructure), often via joint venture partnerships (Savills, 2020).

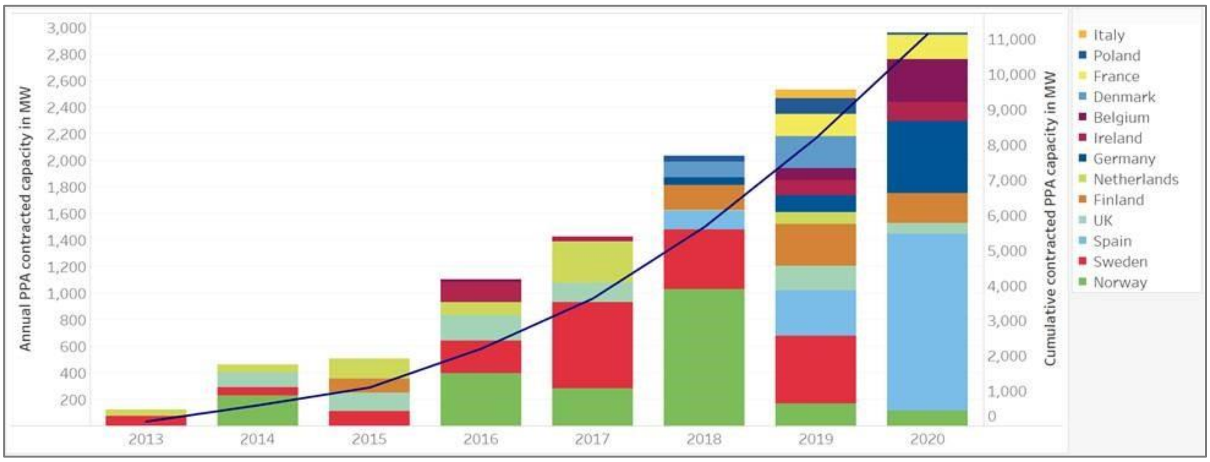
In parallel to this dynamic of investment in DCs, it is also worth highlighting the evolution of PPAs in Europe. The upward trend did not pause or slow down during the pandemic, on the contrary, 2020 turned out to be a record breaking year in terms of PPAs with almost 4GW signed compared to the previous record of 2.5 GW in 2019 (RE-Source, 2021). The demand for renewable energy is spread throughout Europe, with PPAs signed in no less than 13 different countries. Spain and Germany lead the way, but significant PPAs have also be signed in Finland, Ireland, the UK and Denmark. While three quarters of the renewable PPAs signed in Europe are based on wind power, there has been a strong increase in solar contracts in Spain. ICT continues to be the sector signing the largest PPAs, followed by heavy industry.

Figure 9: Power purchase agreements in Europe

(a) by sector



(b) by country



Source: RE-Source, 2021.

4.1.3 What is the geographical distribution of current capacities and new investments within Europe?

At regional level, the largest DCs are located in Northern and Western Europe. These regions were responsible for 82% of DC energy consumption in 2018 (Montevecchi et al. 2020). This predominance applies particularly to hyperscale centres (Savills, 2020).

This density in Northern Europe is partly explained by meteorological characteristics such as ambient temperature and humidity. These have a significant impact on energy consumption, given the load of the thermal control system (Bertoldi et al., 2017). Hence, equipments in this zone are able to achieve a good level of energy efficiency, on average. The Nordic region is also characterised by a highly reliable supply of energy, particularly renewable energy, with some of the most efficient networks in Europe, as well as often competitive electricity prices.

There are various indications that other markets may emerge. For example, the effects of Brexit on the attractiveness of the United Kingdom is likely to be negative. In other 'hotspots', such as the Netherlands, the density of investments already implemented raises questions about the continuity of major flows. Various analyses shed light on a movement to extend investment flows to other countries such as Italy, Austria, Spain, Switzerland and Poland (Research and Markets, 2021).

Box 7: Why did Amsterdam decide on a moratorium on new DC projects?

Hosting 30% of Europe's DCs, the municipality of Amsterdam approved, in the summer of 2019, a one-year suspension on issuing permits for new units, as local authorities were concerned about the increasing pressure on the electric grids and the associated urban planning. During this pause, authorities organised public consultations with stakeholders to draft environmental and energy efficiency rules for DCs, as also required by the 2016 Environmental Act of the Dutch Government.

The authorities stated that the new regulations will require the industry to use green electricity, while also transferring, free of charge, residual heat that will be used for district heating, an option which the industry claimed to have been offering anyway (Amsterdam.nl, 2019; Datacenterknowledge.com, 2019). At the same time, the DCs' association continuously called for the state-run grid company to invest in the infrastructure required to accommodate the increasing needs of the industry. While the investments have not been completed, power capacity was not seen as an immediate issue by the association, as the grid still has sufficient reserves.

Apart from energy-related issues, companies operating DCs have acquired significant spaces in the city contributing to the already-existing challenges of housing and social housing in Amsterdam. Moreover, concerns related to the design of DCs were also raised, as some of the new buildings are not in accordance with the city's historical architecture (Datacenterknowledge.com, 2019).

Despite the halt in new projects, the Amsterdam DC market increased significantly in 2020, adding an equivalent of 51 MW. At the same time, alternative destinations, in other cities of the Netherlands, were explored by investors (Dutchdatacenters.nl, 2021).

Over the course of one year (2019-2020), dialogue between the authorities and industry resulted in agreement on a number of sustainable growth measures, which are in place since 2020. New DC projects located in Amsterdam will have to be developed only in 4 designated areas (Amstel II, Port/Port City, Schinkelkwartier, and Science Park), will have to use multiple floors of a building, as much as technically possible, and will meet specific requirements in terms of energy efficiency and sustainability including a maximum PUE level of 1.2 (Dutchdatacenters.nl, 2020).

4.1.4 What are the consumption levels of European DCs and how are they likely to evolve?

In a report by Bertoldi et al. (2012), the total DC electricity consumption in the EU in 2007 was estimated to be 56 TWh. In 2015, the European Commission (2015) estimated that the electricity used by DCs was 78 TWh, which is equivalent to 2.5% of total EU-28 electricity consumption.

More recently, according to the study of the European Commission (Montevecchi et al. 2020), the electricity consumption of DCs was around 2% of European consumption in 2010, 2.7% in 2018 and, depending on the scenarios, could vary within a range of one to three percent in 2030 (but not more than 3.2% if current trends continue). This estimate was for cloud computing DCs, which include ‘hyperscale DCs plus an estimate for other DCs used exclusively for cloud services’ (Montevecchi et al., 2020, p.57). A recent estimate from the same underlying source suggested demand had reached 3.2% in 2020, in the light of pandemic effects on demand.[44] Total DC demand would be higher than this, though it is not clear by how much.

Four scenarios are considered:

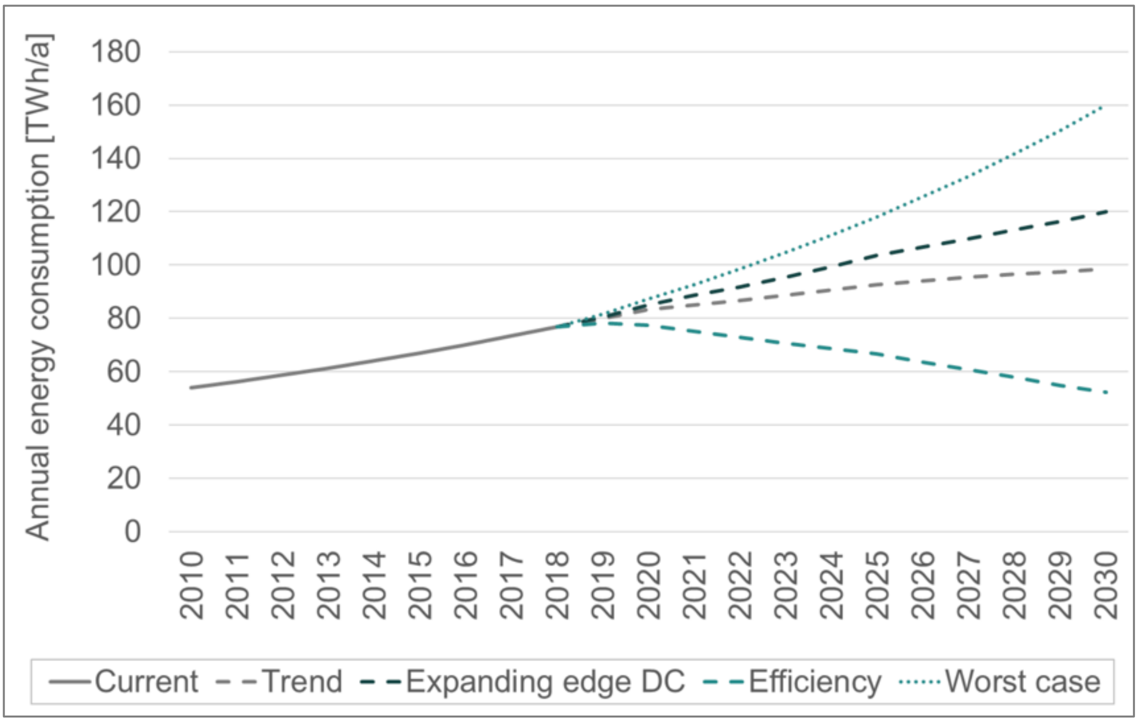
1. **Trend Scenario**: equipment sales and increases in the efficiency of computer hardware and DC infrastructure continue to grow as they did in the years 2010 to 2018. This would mean that DC energy consumption would increase to 98.5 TWh p.a. by 2030.

2. **Expanding edge**: edge DCs will account for 40% of the total server capacity. As edge computing is expected to be accompanied by a significant increase in the total amount of data to be processed, the energy consumption could reach around 120 TWh p.a.. However, if the edge DCs are built to substitute computing in large centres, it may be possible that energy consumption will not increase proportionally.

3. **Efficiency**: Once all available efficiency potentials have been exploited, it will be possible to reduce the energy consumption of DCs in Europe to the 2010 level (52 TWh p.a.).

4. **Worst case**: current growth will accelerate further with lower efficiency gains. An increase in DC energy consumption up to 160 TWh p.a. in 2030 is possible.

Figure 10: Possible scenarios for the development of the energy demand of DCs in Europe



Source: Montevecchi et al., 2020, p.62.

[44] 87 TWh with EU-27 demand of 2565 TWh + UK demand of 287 TWh in 2020 (Eurostat and BEIS). See: https://www.borderstep.de/deutlicher-anstieg-des-energiebedarfs-der-rechenzentren-im-jahr-2020

Comparing Montevecchi et al. (2020), with Andrea and Elder (2015) it is striking to observe that electricity demand in 2020 is much lower than projected (see Koronen et al.. 2020). Andrea and Elder (2015) were predicting electricity demand in 2020 nearly three times the actual level, while frozen energy efficiency would have resulted in even higher electricity demand. Thus past predictions on DC energy consumption have been badly overestimated at the aggregate European level, even though data traffic levels are, if anything, higher in reality than past predictions. This is because of the underestimation of efficiency improvements.

Projections of DC demand for electricity should be set against the wider energy and electricity context in the EU. EU-27 final energy consumption peaked in 2006 and in 2019 was 6% lower than at the peak.[45] EU-27 electricity demand peaked in 2008 and in 2019 was 2% lower than at the peak.[46] Overall energy and electricity demand were barely growing across the EU before the pandemic.

4.1.5 What should be concluded from these perspectives?

Clearly, Europe is not immune to the debate surrounding the prospects for growth in DC-related energy consumption. The key factor will be whether the efficiency gains observed over the decade continue, accelerate, or stagnate.

In addition to the issue of efficiency, there are structural transformations in the DC sector, such as the rise of large-scale DC or the development of edge computing, as well as the possibility for integration into local energy networks, contributing to the needs of the grid or to the use of recovered heat.

These issues are particularly relevant as Europe has decided to define more ambitious decarbonisation objectives for 2030, with a reduction in emissions of at least 55% – with increased needs for flexibility and energy storage.[47] Moreover, the health crisis may have brought structural changes to the use of digital technology with potential substitution effects, especially with respect to use of transport.

However, rather than focusing on electricity consumption alone, the main issue will be the carbon footprint and, within a Union whose electricity sector will be in the process of accelerated decarbonisation, the way in which the deployment of DCs fits positively into this dynamic. The question will be to balance the contribution of DCs to investments in renewable energy and to the emergence of innovative local energy systems with the complexity they add by increasing the demand for electricity in certain locations.

This leads us to consider that, in addition to estimating the prospects for DCs and scoping the potential for the development of associated services on an EU-wide scale (Montevecchi et al. 2020), we should focus on the investment-intensive parts of the Union via a number of case studies.

As Kamiya and Kvarnström (2019) show, DC energy consumption is more of a local than a global issue, with clusters of hyperscale DCs emerging in the most favourable locations, putting pressure on grids and energy systems, that are already facing the challenges of the energy transition. This is particularly acute in smaller countries of the EU and the EEA.

[45] Source: Eurostat NRG_BAL_C Available for Final Consumption.
[46] Source: Eurostat NRG_CB_E Available for Final Consumption.
[47] The share of nondispatchable electricity in the EU electricity system may exceed 50% by 2030.

4.2 A comparison of the attractiveness of different European cities for DC investments

DCs are highly clustered in Europe. Thus the local drivers of DC clustering are important in considering where they locate now and might locate in the future. We begin our discussion of local factors by comparing a sample of European cities, before looking at a couple of detailed examples from Ireland and Denmark.

While the choices that DC owners make are based on a complex set of calculations, it is important to understand the broad range of local conditions in Europe that explain the development of new DCs, both with an impact on business developers, as well as on the energy and climate sectors. Box 8 considers how local opposition to DCs can be overcome, in the interesting case of Luxembourg.

Box 8: The experience of Luxembourg

The recent evolutions in Luxembourg are illustrative of the complexities surrounding the local rather than the aggregate impact of DCs (Datacenterdynamics, 2021). For several years already, the country decided to attract digital investments in order to diversify from financial services and benefit from the economic spillovers of a dynamic sector (Binsfeld and Whalley, 2019). As such, it has set up a number of incentives, in addition to its inherent attractiveness coming from political stability, appropriate climate and strong telecom and energy infrastructure.

The strategy has been successful in attracting DC investment. In 2016-2017, after high-level discussions, Google announced its choice of Luxembourg as the host of its €1 billion investment in a new DC. Since then, the company has faced numerous hurdles, mainly linked to local opposition. At first, a local farmer refused to give up a plot of land, but was finally convinced by the Government. Subsequently, a local initiative group was started with the aim of actively opposing the construction of the large DC in Bissen, 25 km from the capital. The group cited energy and water use as main concerns and wondered whether the low number of jobs created – about 100 – would be worth the significant tax breaks offered by the Government. While local officials did not oppose the project in principle, they did request more transparency from Google about the DC's land, energy and water needs.

Finally, after lengthy discussions involving the Prime Minister and other high-ranking officials, the Municipal Council gave the green light in October 2020 and the Ministry of Interior approved the project in March 2021, after years of delays. When completed, the DC will be the largest electricity consumer in the small country. While the local population is still divided on the subject, the agreement involved the developer committing to a number of conditionalities, including the use of non-potable water for cooling. The precedent is likely to add to the pressure on DC developers to be more transparent and engage more with local stakeholders, given the high impact they have on matters of great public interest such as noise, land-use, energy and water. Better integration, environmental safeguards and positive spillovers are becoming central to DC development.

Our assessment takes into consideration European cities with a high number of DCs (Bertoldi et al. 2017). Additionally, as baseline scenarios, we also included the EU-27 figures, as well as the number for Prague (Czech Republic), a city without high-scale DCs (at the time of writing). At the same time, the selection of cities included the main data demand hubs (such as financial centres), but also considered a diverse set of municipalities, in terms of geography (thus, weather conditions), fiscal incentives or energy mix and carbon footprint.[48]

Indicators considered for each city (*the higher the value in the graph, the better*):

- **Average annual temperature [^{O}C][49]** - Local levels for each city considered. Cooler regions are less energy intensive, thus they consume less electricity than cities with warmer climate conditions.
- **European FTTH/B ranking (2020) [%][50]** – As DC developers are critically influenced by the level of wide area network (WAN) in their decision to select a location, the fibre to the House/Building (FITH/B) are critical indicators for local fibre capacity.
- **Average electricity price for non-household (in H1 2020) [€/KWh]**[51] – Although most DC are closing bilateral PPAs with renewable producers, this indicator is always important to understand the investment opportunity in a city.
- **Fiscal incentives (2021) [0-100 Score][52] –** The existence and the extent of fiscal incentives – for businesses, in general, or for DCs, in particular – are important elements considered in the selection process of a new DC destination. The score is provided by the Corporate Tax Haven Index.
- **Proximity from high data demand [km] –** High data demand is a critical factor in selecting the city for a new DC, as the closer it is from the source of the demand, the better/faster services it can offer (especially in the financial sector).
- **Grid reliability (SAIDI at national level, in 2019) [hours/year][53]** – The System Average Interruption Duration Index is key in understanding how reliable the local grid is.
- **Network adequacy level (LOLE for 2025) [hours/year][54]** – Loss of load expectation (LOLE) is the number of annual hours, in which the electricity generation sector is unable to meet the demand, thus an important element to evaluate the opportunity of developing a new DC.
- **Impact of additional 100 MWh on peak demand (2018) [%][55]** – It is important to properly assess the impact of a potential 100 MWh consumption of a new DC on the highest hourly load, in order to evaluate the stress situations of the local grid.
- **Share of RES in Energy Mix (in 2019) [%][56]** – As the development of new DCs raises environmental concerns, it's important to evaluate the share of renewable generation in the total electricity supply.

[48] For an academic discussion of data centre siting considerations see Ansar et al. (2019).
[49] Source: https://en.climate-data.org/
[50] Source: https://www.ispreview.co.uk/index.php/2020/04/uk-creeps-up-2020-ftth-ultrafast-broadband-country-ranking.html
[51] Source: https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_205/default/table?lang=en
[52] Source: https://cthi.taxjustice.net/en/
[53] Source: https://govdata360.worldbank.org/indicators/h2d96dbda?country=CZE&indicator=42570&countries=IRL,ISL,DNK,DEU,GBR,CHE,ITA,ESP,PRT,SWE,POL&viz=line_chart&years=2014,2019&indicators=944
[54] Source: https://eepublicdownloads.entsoe.eu/clean-documents/sdc-documents/MAF/2020/MAF_2020_Executive_Summary.pdf
[55] Source: https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2018_web.pdf
[56] Source: https://www.iea.org/fuels-and-technologies/electricity#data-browser

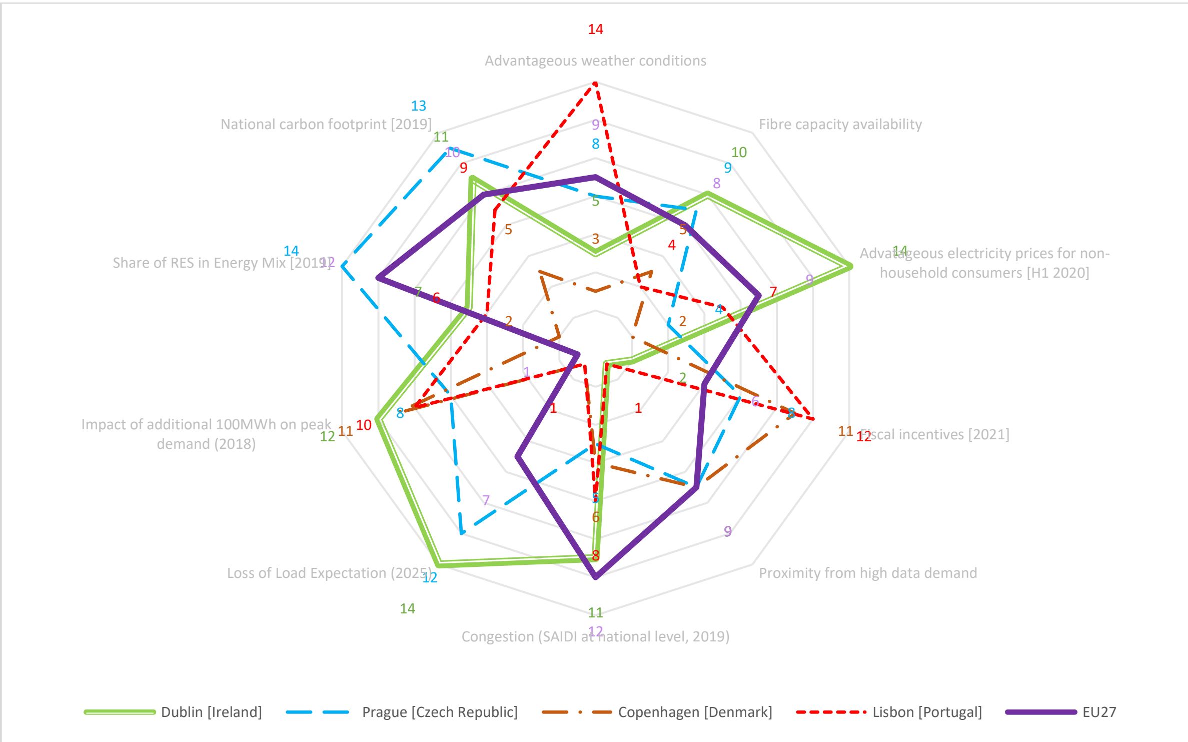
- **National carbon footprint (in 2019) [gCO_2eq/kWh][57] -** Similarly, it is relevant to couple the previous indicator with the national carbon footprint level, to properly understand the climate impact of a new DC.

The absolute data is available in Annex 1.

The following graph showcases the ranking of a selection of European cities, including Dublin and Copenhagen which feature prominently in our case studies, based on the above-described criteria. The more favourable the ranking (1=most favourable; 14=least favourable), the more suitable a DC location is and the closer a city is to the graph's centre. Moreover, Annex 2 and Annex 3 feature similar analysis on additional European cities.

A striking observation from these representations is that all of the cities with existing clusters of DCs excel in several criteria compared to the EU-27 average and to a city like Prague, with no hyperscale DCs. By contrast, Lisbon has recently been announced as a location for a new hyperscale DC.[58] The other observation is that, clearly, energy considerations are not the only criteria on which DC location decisions are made and that favourable performance on energy criteria are not a necessary condition for being attractive as DC location. Thus, while some DCs are located in northern cities with lower temperature, high renewable energy shares and low carbon grids, not all of them are. Equally there is variation across energy criteria. High renewable energy shares, low carbon electricity, lower temperature, low loss of load expectation and available generation capacity do not necessarily go together.

Figure 11 - Attractiveness of different European cities for DC investment



[57] Source: https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-3/assessment
[58] Source: https://www.capacitymedia.com/articles/3828364/portugal-to-get-42bn-450mw-data-centre

Next, we look in detail at two important case studies from Ireland and Denmark, where DC demand seems set to constitute a large part of national electricity demand by 2030.

4.3 Case study 1: Ireland

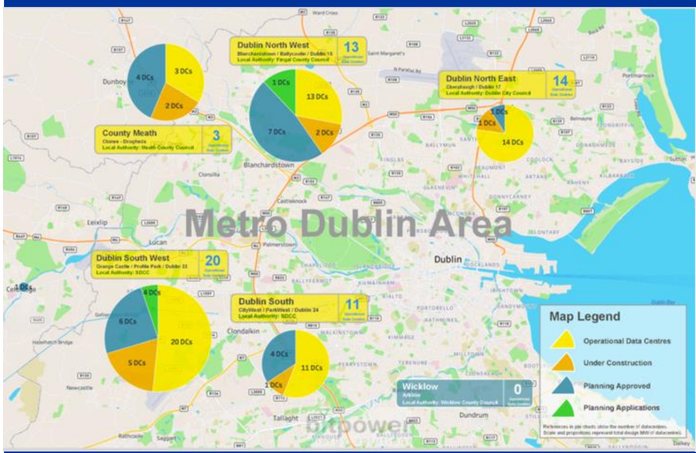
The reasons for selecting Ireland as a detailed case study are obvious given the high concentration of investment in the Dublin region. The energy regulator has recently (29 September 2021) issued a statement (CRU, 2021b) on the measures to be taken to ensure security of supply in the face of the large anticipated increase in demand from DCs in the next few years.

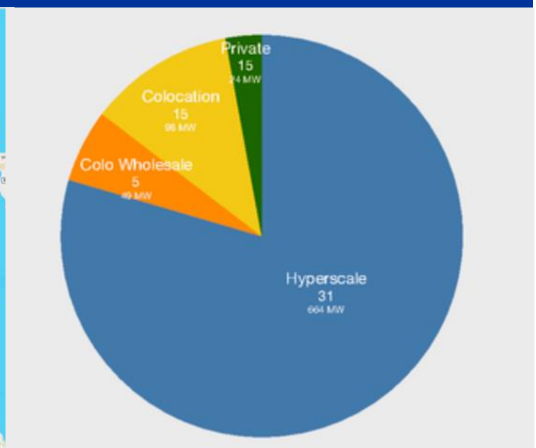
The aim here is to document both the dynamics of these investments and the effects in terms of energy consumption and energy networks. Beyond that, it will be a question of identifying the specific regulations implemented, the local economic spillovers, and the specific models experimented to promote the integration of DCs within Ireland's decarbonisation objectives.

Box 9: The predominance of hyperscale investments in the Dublin Region

There are 66 DCs operational DCs in Ireland as of the end of 2020, representing a total capacity of 834 MW. 31 of these are directly operated by hyperscalers, which account for 80% of the capacity. Five are leased wholesale DC, 15 are co-location centres and the remaining 15 are smaller 'private' centres operated by telecom operators and small suppliers.

EirGrid reports that it has 26 connection agreements in place for an additional 1800 MW of Maximum Import Capacity for data centers, with additional connection requests for 2000.

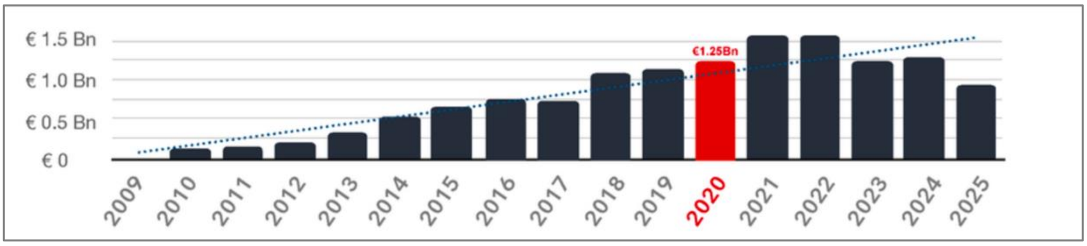




Source: Host in Ireland-Bitpower, 2020, p.8.

4.3.1 Background and public policy in the ICT sector

Figure 12: Investment flows in DCs (2009–2025)



Source: Host in Ireland-Bitpower, 2020, p.8.

Over the past decade, Ireland has attracted many of the major ICT players and become a European hub for multinationals seeking to host their digital assets.[59] Ireland's national industrial policy objectives include the ambition to cultivate this attractiveness to become Europe's digital economy, and more specifically, to strengthen the DC sector.

Ireland's stated advantages in terms of DC location are significant (HostinIreland.com, 2017) and in line with the analysis just outlined:

- Proximity to key markets (as an EU Member State and the only English-speaking country since Brexit);
- Availability of telecommunications infrastructure both to the rest of the EU and to the US;
- Current renewable power generation and stated potential for the development of further renewable energy (particularly wind power);
- Favourable climatic conditions;
- Young and skilled workforce[60]; and
- Overall an attractive fiscal policy and legal framework.

The Irish authorities recognise the capacity and the need to take into account the cost implications. In addition, they are aware of the various structural effects, notably with regard to access to energy but also constraints linked to the fibre network[61] and, more generally, the problem of allocating investment evenly throughout the territory to counterbalance the clustering of greater Dublin.

For example, the Commission for Regulation of Utilities has issued a Consultation Paper in 2021, presenting the perspective of the system operator on the growth in DC electricity demand (CRU, 2021). The paper underlines the challenge in meeting the energy requirements of DCs as large energy consumers of strategic importance for the local economy and global connectivity, while pursuing decarbonisation with various public support instruments, including capacity remuneration mechanisms. The paper encourages DCs and the system operator to explore ways to avoid adding

[59] More generally, Ireland has proven to be a popular destination for foreign direct investment (FDI), hosting nine of the top ten global ICT firms: https://www.idaireland.com/doing-business-here/industry-sectors/ict. This attractiveness has been confirmed on the Chinese side, with the announcement of TikTok to invest up to $500 million to build its first ever European data centre in Ireland. The data centre is expected to be operational by 2022.
[60] The Irish population has the highest proportion of people under 25 in the EU.
[61] Government Statement on the role of data centres in Ireland's enterprise strategy, 2018.

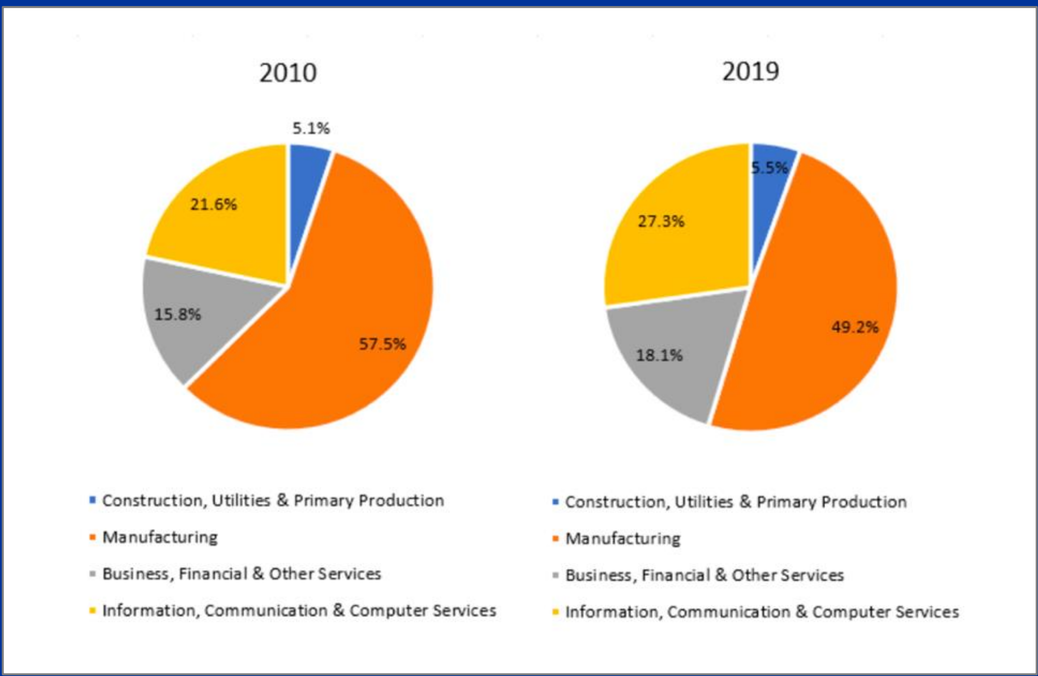
demand to constrained locations, to encourage the use of dispatchable generation and enable more flexibility of demand (CRU, 2021, p. 16).

The strategic importance of DCs is reflected in the project 'Ireland 2040 National Planning Framework' which sets out the approach to spatial planning.[62] Minister Pat Breen summed up the tensions induced by the growth of DC during the 2010 decade: *"We are not blind to the challenges in terms of the planning process and energy consumption that will need to be addressed. Unconstrained growth, or growth on an ad-hoc basis is not desirable from the State's perspective, and that is why we have undertaken a planned and strategic approach.[…]. The Government recognises that there is a need to take account of community and public concerns around individual projects while also ensuring timely decision making in the planning process. Ireland's success in attracting data centre development also creates challenges in providing the energy infrastructure necessary to facilitate further expansion of the sector."*[63]

Box 10: ICT employment dynamic driven by foreign investment

Overall, the ICT sector increased from 21.6% in 2010 to 27.3% in 2019 in total development agency assisted employment in Ireland. Looking specifically at foreign companies, this sector accounts for 38.1% of total jobs compared to 30.8% in 2010.

Taking all sectors together, the Dublin region concentrates nearly one in two development assisted jobs in 2019 (43.8%, compared with 38% 10 years ago): the growth dynamic in the region has been particularly driven by foreign companies, whose employment has almost doubled over the decade (+85.8%). Comparatively, the progression in the South-East region was 'only' +45%.



Source: Department of Jobs, Enterprise and Innovation, Annual Employment Survey 2019, May 2020.

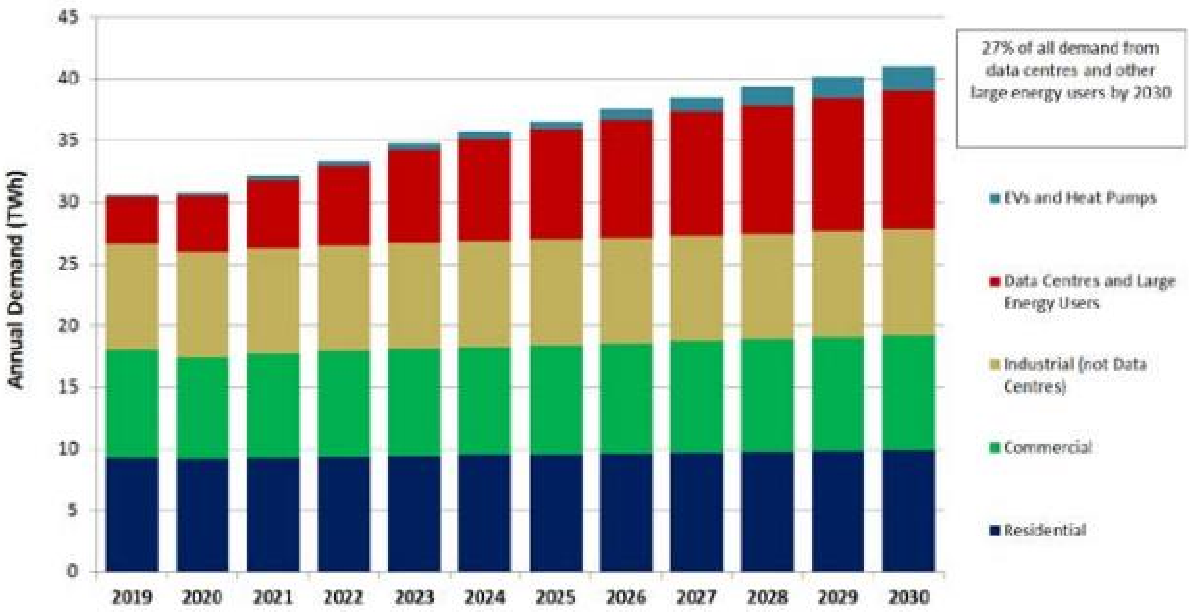
[62] Description of project Ireland: https://www.gov.ie/en/campaigns/09022006-project-ireland-2040/
[63] Keynote address by Minister Breen at the Data Centres Ireland Conference, Wednesday, 21 November 2018. Pat Breen was Minister of State for Trade, Employment, Business, EU Digital Single Market and Data Protection.

4.3.2 The rise in demand for electricity from DCs in the 2020s

The public debate in Ireland on the conditions for growth and DC has crystallised around the forecast growth in electricity demand provided by EirGrid up to 2030 (EirGrid-SONI, 2021). The Irish TSO estimates that this demand will be the main driver of growth in electricity consumption in Ireland over the decade, based on projects that are currently being connected or have been the subject of enquiries.

On this basis, EirGrid has drawn up three scenarios differentiated according to whether the DC projects currently under development or under review would be partially or fully realised. Based on the low or high assumptions, the growth in electricity demand from 2021-2030 years varies between 17% and 43% (EirGrid-SONI, 2021 p.74-76). In the medium scenario, DC demand could account for 27% of all electricity demand in Ireland by 2030.

Figure 13: Total electricity requirement forecast for Ireland 2021-2030



Source: EirGrid-SONI, 2021, p. 24.

While the Irish electricity system started from a position of significant surplus, this is eroded by forecast demand growth and by the closure of some thermal power stations, which will lead to growing deficits from 2026 onwards, due in particular to the closing of coal-fired generation in 2025 and the uncertainties linked to the maintenance of units using peat. This was foreseen, but as in many other countries, it is proving difficult to add transmission lines, zero carbon generation and reserve capacity.[64] Going forward the anticipated demand growth outpaces the delivery timelines anticipated for traditional sources of reliable capacity such as combined cycle gas turbines (CCGTs).

The IAE - Irish Academy of Engineering (2019) has made an assessment of the additional investment required to keep pace with rising demand, assuming that some of it will be met by renewable energy

[64] See for example: Everoze (2020) and https://www.businesspost.ie/energy/dublin-energy-shortfall-predicted-after-esb-drops-gas-projects-bea10433

generation, in line with the Government's Climate Change Action Plan, with almost all of the remainder being produced by high-efficiency gas turbines.[65] The conclusion of this analysis is that the planned development of DCs would require an additional investment in Ireland's electricity sector of nearly €6 billion in generation and associated network assets,[66] as well as battery storage capacity involving an additional €2.5 billion investment.

This evaluation represents a first approximation which does not seem to integrate much technical progress in the management of the electrical system.[67] Nevertheless, it has the merit of opening a debate on the importance of investments and adaptation of the electricity network. All the more so as experience demonstrates in Ireland (and across Europe) the considerable time needed to adapt transmission networks. This is pointed out by the Irish Academy of Engineering in another study, expressing its concern "*that insufficient attention is being devoted to the issues associated with the development of the transmission network (National Grid) and that the challenges, if not addressed, will undermine the country's efforts to reduce GHG emissions as planned*". It should also be noted that energy transport infrastructures are not the only ones for which problems of community acceptability may arise. In 2018, Apple was obliged to put an end to a hyperspace project in Galway, in the West of the country, after three years of objections from opponents and hearings in court. The opponents have protested against the environmental impact on the region. At the same time, the project also had a significant number of supporters at the local level.

4.3.3 The levers to accompany the dynamics of electricity demand

Industry wide efficiency improvements are not likely going to address the problem of hyperscale investment in Ireland.

On the other hand, even if remarkable progress can be observed, the Irish electricity mix is far from being among the least carbon-intensive in Europe, though the trend is improving with increasing renewable electricity shares over time. In 2019, Ireland ranked 19th in the EU28 in that regard. This characteristic is common to some other Member States that host important DC investments, for example, the Netherlands ranked 21st (EEA, 2020). However, CO_2 emissions associated with DC activity accounted for only 1.6% of emissions linked to energy use in 2019. The outlook for 2025 is to keep emissions below 2%, despite the doubling of capacity (HostinIreland, 2020), and despite the fact that consumption in this sector is expected to account for between 20 and 25% of the national total. However, if emissions intensity does not fall as originally envisaged due to the need to increase fossil fuel intensity to maintain security of supply, the outturn emissions may turn out to be higher.

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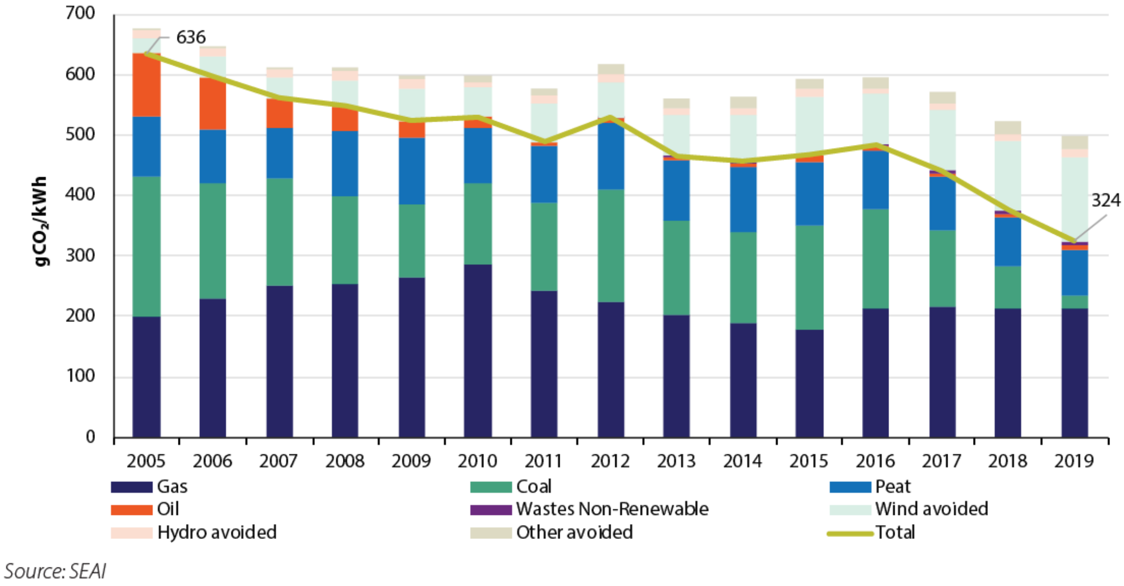
[65] This analysis is based on the assumption that 50% of the incremental electricity is generated from onshore wind, 25% from offshore wind and 25% from solar photovoltaic energy.
[66]. In addition, the report stresses a difference in the regulatory capital recovery period for transmission and distribution assets (50 and 40 years respectively), compared to a much shorter lifecycle for data centres.
[67] Investment needs will depend on many variables, including the spatial location of future DCs, power generation facilities and interconnection capacities. The hypothesis that the need for additional storage will be based entirely on batteries is also strong, as underlined in the report. For example, with a large fleet of electric vehicles (500,000, for the record), it can be assumed that part of the flexibility could be provided by V2G mecanisms, or by DCs demand side management capacities in the future.

Figure 14: Carbon intensity of the Irish electricity production

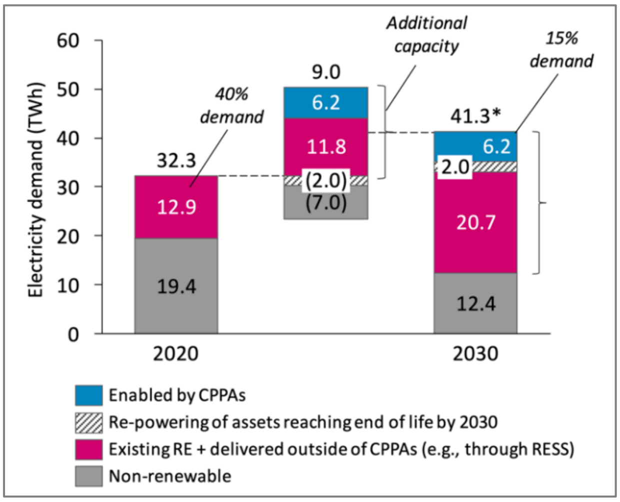


Source: Sustainable Energy Authority of Ireland, 2020, p.37.

Understanding this level of performance involves observing the sourcing strategies of DC operators, in particular through PPAs. This tool is part of the government's climate action plan, which sets the objective that 70% of all electricity consumed by 2030 should come from renewables, and a sub-objective that 15% of electricity consumption should come from renewable electricity based on PPAs. The rationale put forward by public authorities is that, given that intensive energy consumers are responsible for a large and growing share of total electricity demand, the requirement to base a proportion of the renewable electricity on PPAs will help to ensure a fair distribution of the costs associated with achieving this target. This objective is also consistent with the Government's statement on the role of DCs in Ireland's industrial strategy, seeking to balance the positive impacts that DCs will have on job creation and the challenges in terms of security of supply and climate and energy objectives.[68]

[68] Government Statement on Data Centre in Ireland's Enterprise Strategy, 2018.

Figure 15: Renewable electricity penetration targets (2030)[69]



Source: Baringa, 2020, p. 4.

According to a government-commissioned study (Baringa, 2020), this target will mean that up to 6 TWh of additional electricity generation by 2030 will be supported by PPAs, i.e., about 35% of all new generation capacity, equivalent to 2.3 GW of onshore wind power or more than 6 GW of photovoltaic solar power. Baringa warns, however, that it is not certain that onshore wind will be sufficient. Offshore wind and solar could become more competitive later in the 2020s, leading to greater deployment in the second half of the decade. This study also sheds light on the specific value of the PPAs for project leaders, in terms of 'reputation', which is summarised in the testimony of one company: "*Some corporates are gold standard and need additionality, silver standard is GoOs from Europe. Bronze is 'I'll buy GoOs from old hydro in Sweden'*."

However, the cluster in the Dublin region remains central for new projects. There are currently 11 DC projects under construction in the Dublin metropolitan area, with an average size of 27 MW (HostinIreland, 2020). While the location of DCs outside the Dublin region might ease grid constraints, it will not address the issue of national energy security caused by the difficulties in adding sufficient generation of the right type anywhere in Ireland.

4.3.4 Conclusion on the sustainability of the Irish strategy

Undoubtedly, the option taken by Ireland to put information technologies and the associated services at the heart of its industrial strategy has been a resilience factor. For example, in 2020, slightly more than a quarter of export activity has been in this sector. This is one of the only areas of activity that have continued to grow in 2020. Specifically concerning DCs, their deployment will have made a direct and indirect contribution of around €10 billion to the Irish economy over the decade 2010, without taking into account the effects induced by the use of associated services (IDA Ireland, 2018).

Ireland's strategy is to continue to rapidly reduce the carbon footprint of its electricity system, in particular by exploiting its strong wind power potential, both onshore and offshore. This potential could even lead to over-capacity. The rationality of this strategy is explained by the Irish Academy of Engineering: "*One could indeed argue that there is little point in constructing large amounts of*

[69] The Renewable Electricity Support Scheme (RESS) is a central element of the National Energy and Climate Plan 2021-2030. RESS auctions will be held at frequent intervals throughout the lifetime of the scheme. https://www.gov.ie/en/publication/36d8d2-renewable-electricity-support-scheme/

renewable generation in Ireland and then exporting its output at exceptionally low prices"[70] […] but "*the value add of a data service is greater than the renewable electricity alone. Add to that, the infrastructure to move data already exists whereas the infrastructure to move the electricity does not*" (IAE, 2019). In other words, the prospect is that the best use of the Irish wind is to transform the electricity generated into ICT services, which may continue to justify the strong growth of the DC industry. This remains a challenging goal to realise in practice.

However, this strong growth leads to an ecosystem under pressure. While the power sector can add sufficient capacity by 2030, the closure of thermal-based generation facilities will open a period of tension in the middle of the decade. This does raise a national issue with adding enough reliable low carbon generation. While the growth of other DC clusters outside Dublin (Cork, Galway) can help with transmission capacity problems, assuming that they reduce grid investment requirements. Another factor will be the acceptability of the population for new investments, both in DCs and in electricity production and transmission infrastructures. Meanwhile, the reserve capacity costs for extra generation capacity procured to secure the whole system are covered by all consumers, not just the new loads which cause them, raising the issue of the fair distribution of payment for extra system costs. Finally, the growth prospects have been established without being able to take into account both the effects of the COVID-19 crisis and of Brexit, which could lead to an even greater increase in the demand for DC development.

A key problem posed by DCs in Ireland is that they seemingly add large amounts of inflexible load to a system where more flexibility is required as the generation mix becomes increasingly intermittent. This is in addition to the fact that they add significantly to total electricity demand. EirGrid have recently offered flexible demand connection contracts to new DCs which encourage them to flex their demand in response to the condition of the grid, with EirGrid suggesting up to 500 hours of curtailment might be possible under such contracts. While DC projects are not yet being delayed, it is taking longer to provide them with a connection offer.

The CRU (2021a) consultation highlights the desirability of a more extensive dialogue between DC owners and the system operator in order to facilitate better planning and delivery of both DC owner and system operator requirements. This should include more accurate forecasting of actual demand growth – the bounds are currently very wide - and a greater DC contribution to system flexibility requirements. An industry support group representing DC companies in Ireland (IBEC's Cloud Infrastructure Ireland) has made a written submission to the consultation (IBEC, 2021). They propose: increasing incentives to align required transmission capacity requests more closely to expected usage; increasing incentives on DCs to provide flexibility services; reform of transmission tariffs; and the introduction of location specific transmission pricing. This suggests that the industry is open to supporting better incentive alignment within the Irish grid.

In September 2021, the Irish energy regulator took further action to ensure security of supply in the face of rising demand (see CRU, 2021b). This included seeking to procure additional gas-fired generation capacity, lifecycle extension for existing fossil fuel generation, the priority connection of new generation and advancing of plans to increase both electricity and gas interconnection. It also affirms its desire for more demand responsiveness from data centres.

[70] Since import/export data for 2019 indicates that the price of Irish electricity exports, which take place predominantly when wind generation is high, is less than 50% of the price paid to wind generators for that output under the REFIT regime.

4.4 Case study 2: Denmark

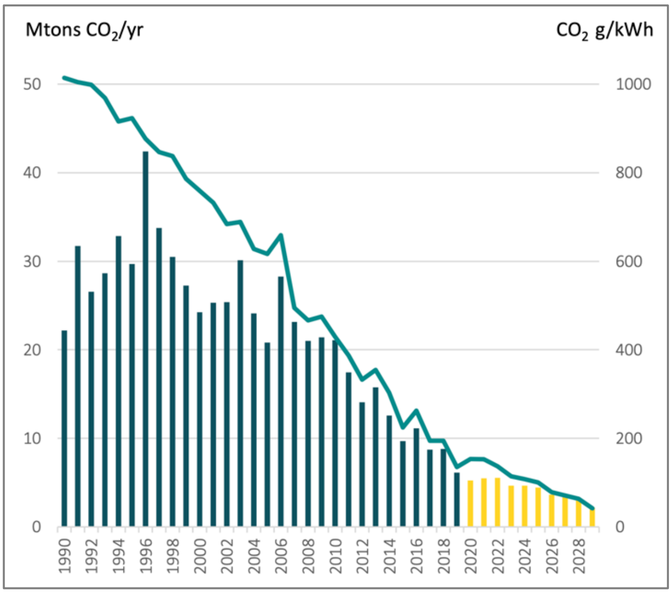
The Danish case is another example of accelerated investment in DCs in a medium-sized European country, in a different geographical and institutional context, illustrating the technological and political adaptations required to accompany this process.

4.4.1 Background and public policy in the ICT area

Until mid-2010, Denmark was a low-intensity DC location, limited to telecom operators and co-location offers. The local market has only taken off in the last few years, which have seen the deployment of several hyperscale projects, attracting all the leading ICT companies. These investments, as in the case of Ireland, are attracted by one of the most open OECD economies when it comes to digital services. Cloud computing is an integral part of many digitisation policy initiatives. A concrete focus is the removal of barriers to the use of cloud computing solutions in the public sector at national, regional and local levels. In addition, cloud computing is driving many other initiatives, including automatic business reporting and data sharing. The recent National Artificial Intelligence Strategy also mentions access to cloud computing solutions as a prerequisite.

This attractiveness stems from various factors. Some are structural, such as the business environment in Denmark, very high in international rankings, others are natural such as the climate which is favourable to the management of heat dissipation from DCs. The quality of the infrastructures is also a factor, for example, 80% of power lines are underground, which protects them from weather events. In addition, recent developments have brought an increased subsea connectivity with the inauguration of a new Havfrue submarine cable, partly financed by DC operators, to link Denmark directly to the east coast of the United States. Finally one should also notice the rapid progress in the decarbonisation of Danish electricity in the last decades.

Figure 16: Emissions and carbon intensity of Danish electricity production [1990-2030]



Source: Statement of environmental impact from Danish electricity and cogeneration production, 2020

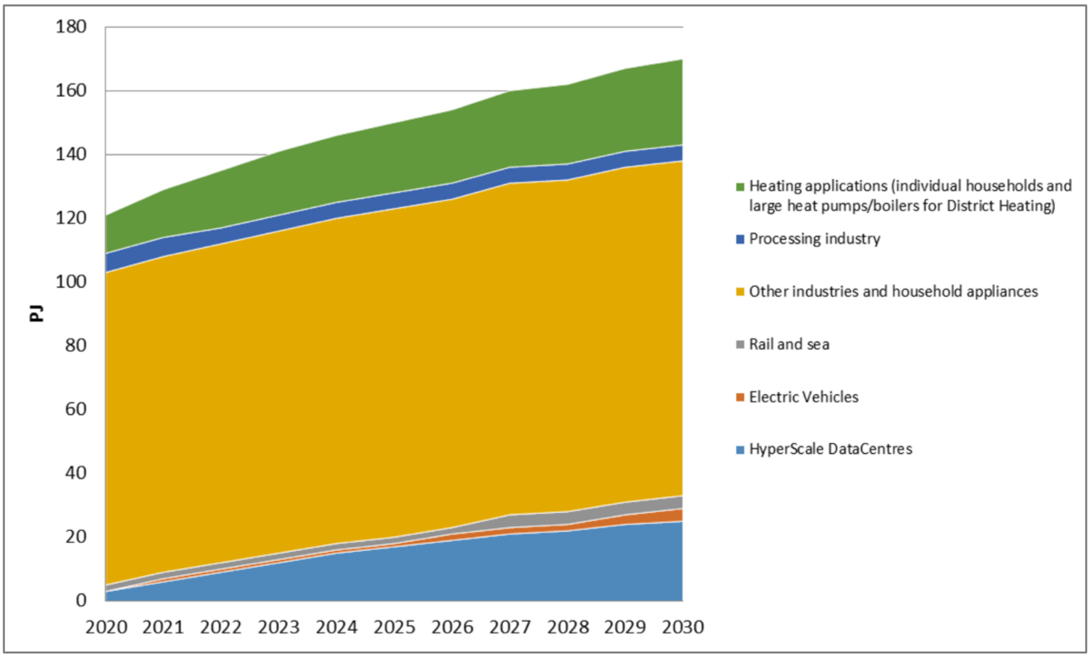
By 2019, average CO_2 emissions from the power sector were down to 126 g/kWh, 40% of the Irish level, placing Denmark ninth in the EU-28 (EEA, 2020). The evolution is remarkable, since in 2010 the average level was still 500 g/kWh, which corresponds to a reduction by a factor of four in only a decade. All in all, the Danish Government has committed itself to an ambitious climate policy, which aims to reduce national emissions of greenhouse gases by 70% in 2030, relative to 1990 levels, having already realized a reduction of 38% (Danish Ministry of Climate, Energy and Utilities, 2019a).

This could further reduce emissions from the power sector by a factor of three by 2030, with performances fairly close to full decarbonisation.

4.4.2 The rise in demand for electricity from DCs in the 2020s

According to the Danish Energy Agency, the demand for electricity could grow by 40% by 2030, largely under the pressure of additional consumption by DCs and excluding electric vehicles, another source of increased demand for electricity over the period. In 2015, the Danish IT sector accounted for 0.5% of national electricity consumption (Statistics Denmark, 2020).

Figure 17: Electricity consumption excl. grid losses 2020-2030 [Pj]



Source: Danish Ministry of Climate, Energy and Utilities, 2019a, p.135.

This perspective of growth has been apparent in the Danish agency's forecasts for several years and is constantly confirmed, while stressing that the forecasts are affected by large uncertainties. The problem is therefore to understand, around this central scenario, what could be the different trajectories of evolution of the demand specific to DCs, depending in particular on technical progress, and how to adapt the electrical system accordingly.

A study commissioned by the Danish Energy Agency (COWI, 2018) developed four scenarios to anticipate the demand induced by hyperscale DCs. The scenarios are driven by the growth in DC workloads, technological developments, and assumptions of Danish market shares.

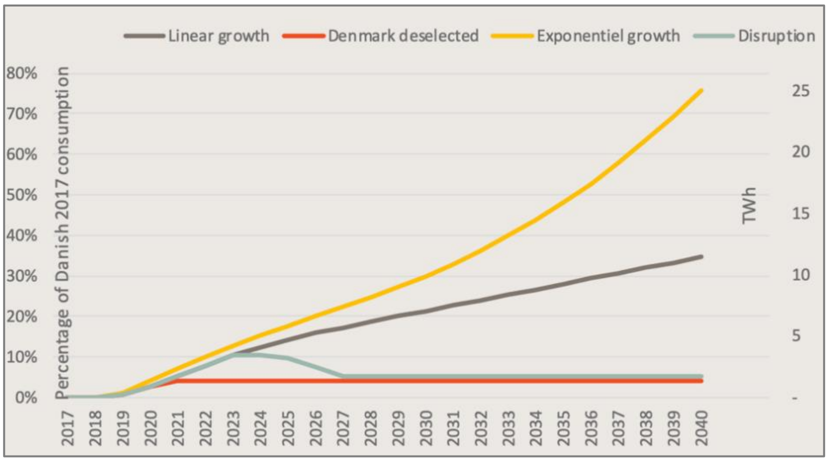
While the purpose here is not to analyse in detail the underlying elements of these scenarios, various observations can shed light on the nature and scope of these uncertainties:

- Firstly, according to this modelling, Denmark is facing an uncertainty that could represent in 2030 around 25% of its electricity consumption (compared to the 2017 level).
- Some of the growth factors are partially under its control, particularly in the context of competition between European regions to attract investment and thus avoid being 'deselected'.
- But other factors are largely exogenous: a 'disruption' could result from technical progress

that is the responsibility of the DC industry, and not just Denmark's capacity to act.

- The same applies to 'exponential growth', which will result from an increase in the load factor of DC, related to changes in uses and processes that will not be steered by the Danish authorities.

Figure 18: Electricity consumption of hyperscale DCs in Denmark in four scenarios



Source: COWI, 2018, p. 16.

This work is echoed by Petrovic et al. (2020), who also models scenarios (up to 2050) of both a sharp decrease in DC power consumption, notably under the effect of technical progress, and, conversely, an exponential increase in the number of hyperscale centres and the associated workload.

4.4.3 The levers to accompany the dynamics of electricity demand

Denmark has many assets to meet the challenges associated with its proactive strategy of attracting DCs. Firstly, the development of the PPA market. In this respect, the Danish context is quite favourable, with many locally anchored companies that have made commitments in terms of reducing their carbon footprint (well represented in the R100[71]) that they need to materialise. These include Lego, Carlsberg, Bestseller, Rockwool, Arla, Aalborg Portland, Novo Nordisk. Thus, the take-off of the PPA market does not rely solely on DC operators. Denmark is also considering promoting the organisation of small businesses in the form of syndicates so that they can access these contracts with reduced transaction costs.

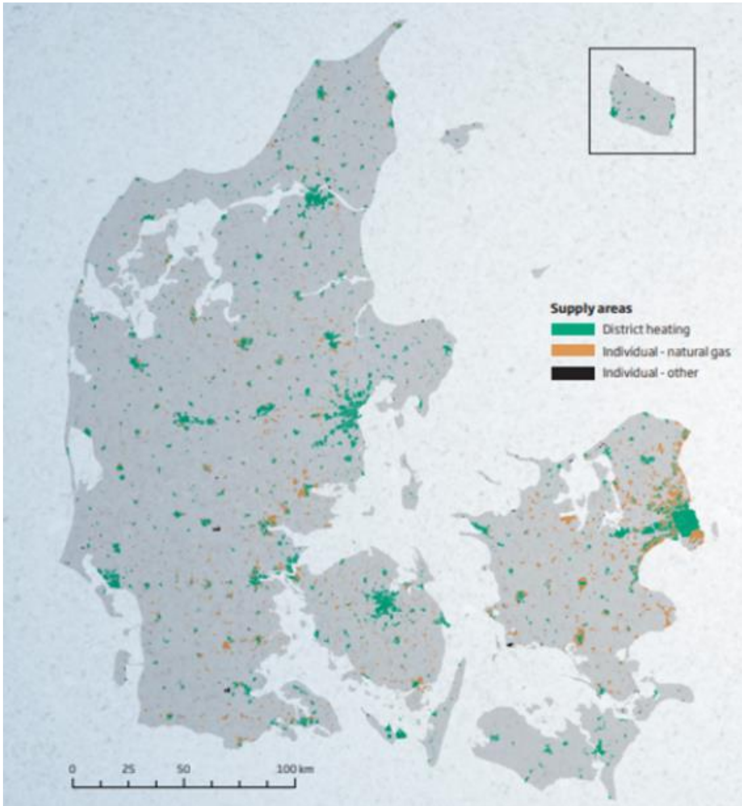
The Danish Ministry of Climate, Energy and Utilities (2019b) has carried out an assessment of the potential of PPA, which considers that, in 2030, between 13-18% of electricity consumption could be covered by this type of contract (i.e., relatively close to the Irish targets). Above all, the Ministry in its analysis highlights that the Danish energy market is fundamentally adapted to the PPA, thanks both to its strong development of renewables and the expertise built up over the last decade. In addition, the disappearance or reduction of renewable energy subsidy schemes in Denmark will force developers or traders to diversify their business models to include PPAs.

Furthermore, an essential advantage of Denmark is the very wide development of district heating, the Danish example of the decarbonisation of the heating and building sector being emblematic. In 2019, the Danish Energy Agency estimated that, without further policy intervention, the share of

[71] RE100 is a global corporate renewable energy initiative bringing together large businesses committed to 100% renewable electricit: https://www.there100.org/

renewable energy in heating would increase from around 45% to 60% by 2030. One of the reasons for Denmark's progress in decarbonising heat is the effort to promote energy efficiency in buildings and district heating. More than 65% of Danish households are connected to a district heating network, which supplies about 50% of Denmark's total heat demand.

Figure 19: Map of district heating in Denmark



Source: State of Green, 2020, p.12.

This opens up the possibility of integrating hyperscale DC in heat networks, which is the case, more generally, in most northern European countries. The recovery of fatal heat, itself produced by a decarbonised energy source, would bring obvious benefits. Part of Denmark's attractiveness stems from the density of heat networks and the prospects of heat recovery, which makes the high commitments to decarbonise DC activities more plausible. However, the optimisation of this potential creates a double constraint, namely the trade-off between the proximity of renewable electricity production facilities and the proximity of heating networks, while taking into account the availability and price of land (Petrovic et al., 2020).

Box 11: The experience of coupling with the Odense heating network

Facebook's DC in Odense captures excess heat generated by their servers and recycles it to provide heat to the local community. In most DCs, air conditioners cool the servers to an optimum temperature of around 28℃ and pump hot air into the atmosphere. Conversely, the Facebook facility in Odense recycles the heat to transmit it to households.The heat is transferred via water-filled copper coils, which connect one of Fjernvarme Fyn's heat pumps to the cooling units in the DC. Warm air from the servers heats the water that circulates in the coils, which is then returned to the heat pump installation. Fjernvarme Fyn's heat pumps then use the hot water to raise the temperature of the water loop that supplies hot water to the radiators in the Odense homes, to heat a local hospital and several other buildings in the surrounding community. Recycling waste heat from DCs is not new in itself. As early as 2008, the Swiss town of Uitikon, outside Zurich, began channelling heat from a nearby IBM DC to heat a local swimming pool. Amazon's headquarters in Seattle has been kept warm with waste heat from a 34-storey DC in a neighbouring district. But the scale of the project set up in Odense is much higher than these other initiatives, with up to 25 MW per hour of usable heat produced, enabling 165,000 MWh to be generated per year, the equivalent of around 11,000 households.

4.4.4 Conclusion on the sustainability of the Danish strategy

The choice of the Nordic countries as a preferred location for investment in large DC seems robust, and these countries would have an even stronger case for investment, assuming that in the near future investors will focus more on sustainability. Furthermore, access to a polar fibre route from China could further reduce the latency time between Asia and Europe, giving the region an additional advantage (Christensen et al., 2018).

Denmark illustrates the challenges that could be posed by the rapid development of DCs, which represent a unique 'historical' experience of inserting an electro-intensive sector over a very short period of time, within an energy system that is itself undergoing drastic evolutions. Denmark's ability to transform its energy system over the last decade is an impressive accomplishment, all the more so as the country has succeeded in deploying an industrial strategy, upstream, particularly in the production of equipment in the wind energy sector. However, in the next decade, Denmark has to face a twin challenge, with the imperative of a new electric transition, combined with the integration of an electro-intensive sector such as DCs. While Denmark has some strong assets to deal with these challenges, in particular thanks to networks that are well suited to harnessing the fatal heat of DCs, the potential evolution of its electricity demand could follow a broad spectrum of scenarios. Public authorities may not have all the levers to steer future developments, which will also depend on technological change, international competition and changes in usage.

4.5 The implications of net zero energy policy for DCs in Europe

In this section we discuss the outline of what net zero means and put DCs in the context of this. Europe is the centre of a climate policy revolution with profound impacts. These impacts have been modelled extensively and they will affect all major sources of electricity demand. We discuss what net zero energy policy consists of, what its technical features are in electricity, heating and transport, the impact of climate change itself on infrastructure, how carbon and hence energy prices are likely to change, the implications for locational pricing within the electricity transmission and distribution networks and the role of local energy markets and associated energy communities. In each case we discuss how expected impacts will relate to DCs.

4.5.1 What does a European net zero energy policy imply for the future?

The EU has strict energy and climate targets. In late June 2021, the EU approved its net zero target for 2050. This means that across the EU-27 and United Kingdom greenhouse gas emissions need to be reduced from c. 5721 m tonnes (CO_2e) in 1990 to zero net (2019 = 4235 m tonnes).[72] Chyong et al. (2021) model the net zero energy system for the EU-UK. In line with the European Commission's own Long Term Energy Scenarios (EC, 2018) they establish a number of key features of the net zero energy system. First, total final energy consumption will be around 67% of what it was in 2018, if the existing system were to be fully decarbonised in line with the target (8246 TWh vs 12347 TWh) (Chyong et al., 2021, p.74). Second, final electricity demand will be substantially higher than it was in 2018 (4175 TWh vs 2812 TWh) (Chyong et al., 2021, p.74). Third, electricity will be additionally important in the creation of hydrogen and e-liquids (e.g., synthetic diesel from hydrogen and CO_2 captured from biomass), increasing the overall primary supply of electricity (6818 TWh in 2050 vs 3629 TWh in 2018) (Chyong et al., 2021, p.74). Fourth, electricity will be heavily dependent on intermittent renewables with onshore and offshore wind and solar providing 78% of electricity (Chyong et al., 2021, p.76). Fifth, heating demand will need to be met by a combination electrification, hydrogen, biomethane and synthetic methane (produced from hydrogen and CO_2). Sixth, much of passenger transport will need to be electrified, but heavy duty transport will require a combination of hydrogen, synthetic fuels and residual fossil fuels. Hydrogen will be a combination of blue hydrogen (cracking of methane and CCS) and green hydrogen (electrolysis of water using VRE). Seventh, while overall energy demand falls and energy efficiency rises, substantial investments in electricity grids, hydrogen and zero carbon fuels, carbon capture and storage are required. Eighth, carbon prices are assumed to be high and rise to €350 (in 2018 prices) per tonne of CO_2 by 2050. Ninth, electricity trade in TWh between European countries increases substantially, by a factor of around three, to facilitate electrification and exploitation of intermittent renewables (Chyong et al., 2021, p.85). There is a significant increase in peak interconnection capacity to facilitate this. Finally, net zero critically depends on both carbon capture and storage (CCS) and negative emissions from the use of combination of biomass with CCS (or BECCS).

It is important to point out that the changes implied by net zero are profound in a 30-year timeframe. Decarbonisation of the European energy system involves reducing carbon by a factor of three relative to the reduction seen in the previous 30 years. Every major consumer of energy is going to be affected. Any large energy consuming sector such as DCs will be faced with these implications arising from the wider net zero impacts on the energy system. Net zero is not just about zero carbon sources of electricity. It is also about how increasingly intermittent sources of supply of electrical energy can be matched to demand in real time. Large inflexible loads will be under increasing scrutiny in a decarbonising electrical system. It is welcome that DC owners are taking the initiative in working with the European Commission to support climate neutral DCs via the Climate Neutral Data Centre Pact against this background.

4.5.2 Some relevant technical features of net zero

4.5.2.1 In electricity

Net zero implies a much more difficult to manage electricity system than we have now (O'Sullivan et al., 2014). A 78% average VRE at the aggregate level raises issues about how to manage fluctuations in renewable fleet output across the day, the season and within local grids. While electricity use for green hydrogen production can be a significant swing demand on the aggregate system there will still, likely, need to be much sharper price signals in the wholesale electricity market across the day,

[72] Source EEA data, see: https://www.eea.europa.eu/data-and-maps/figures/greenhouse-gas-emission-targets-trends-1

the season and by location. Large electricity loads will have to be exposed to price or quantity rationing of their electricity supply. Loads which can flex both their power input (in MWs) and their impact on power quality (e.g., in MVARs[73] which measure reactive power), will enjoy cheaper power relative to those who cannot. There may thus be substantial benefits to own generation and electrical energy storage.

Net zero will require substantial upgrading to power grids at the transmission and distribution levels to handle intermittency but also increased peak electrical demands arising from electrification of heating and transport. Grid users will likely have to pay significantly higher grid charges regardless of actual MWh usage. Again those who can reduce their maximum contracted electrical infeed from the grid will be able reduce the share of the total (rising) grid costs that they will be responsible for.

Increased intermittency suggests that there will be pressure towards the introduction of sharper price signals (Pollitt and Anaya, 2016). This can take a number of forms. First, wholesale energy markets can move to increasingly real-time pricing (five minute intervals or less). For instance, the NEM in Australia has moved to five minute prices. Second, increased use of ancillary services markets for frequency response, voltage support, reserves and security of supply (Pollitt and Anaya, 2021). Here, system operators use markets to acquire the flexible resources that are required to manage the system. EirGrid in Ireland has introduced a range of new ancillary service (DS3 system service) products and is moving closer to real time auctions to help manage its system under its DS3 programme. National Grid ESO in GB has increasingly moved towards shorter term market based procurement of ancillary services. Third, network charges can increasingly be differentiated by location to reflect network constraints and marginal line losses. One form of this is zonal annual connection and use of system charges (as in Great Britain for transmission). A deeper form of such charging might involve locational marginal pricing (LMPs) at the distribution level. These already exist in RTO/ISO markets in the US down to 66kV connections.

Sharper longer term and short term price signals differentiated by location within the electricity grid creates threats and opportunities for large loads. The threat is that electricity charges will generally be higher for large loads locating close to already congested demand centres. This includes DCs near European capital cities. The opportunity is that loads that can respond better to the price signals will face relatively lower average electricity costs.

Net zero may not result in use of sharper price signals. It could result in more use of quantity rationing and priority ordering of loads. At times of extreme system stress prices cease to be effective and the system operator has to instigate load reductions (such as in Great Britain on August 9th 2019).[74] Here loads are disconnected with priority being given to critical infrastructure. Some DCs might be protected in the case of disconnections, but others may not be, depending on their priority status. As we have discussed, DCs usually have an uninterruptible power supply (UPS) to protect the equipment from an outage arising from the main grid.[75] This is usually in the form of a battery capable of maintaining the load for a short time. It could also have a generator attached. This equipment, if so configured, could also be used to supply back-up power to the grid. This UPS and onsite generation could be configured to additionally provide services to the grid. Whether some part of DC demand should be classified as critical infrastructure is not clear cut, as this might result in them being classed as equivalent to, say, a hospital. However, what seems likely is that any new large load being added to the system will be under increasing pressure and financial incentive to demonstrate their ability to serve their own load and/or provide flexibility to the wider grid.

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[73] MVAR = Mega volt-ampere reactive. The need for the addition or reduction of MVARs occurs whens the current and the voltage are not in phase in an AC circuit.
[74] See https://www.nationalgrideso.com/information-about-great-britains-energy-system-and-electricity-system-operator-eso
[75] See Loeffler and Spears (2015) for a discussion of their features.

It is important to point out that the PPA strategy pursued by DC owners can be helpful in promoting net zero if it adds additional renewable capacity more cheaply than would have otherwise been the case. However, corporate PPAs will not on their own ensure the achievement of levels of low carbon generation required by net zero. These will only be guaranteed by government policy. This is because if the overall objective is to decarbonise the grid, hence consumers won't have a choice but to buy zero carbon electricity. The purchase of PPAs by DCs to cover all their electricity demand can accelerate the roll out of renewables relative to interim policy targets (such as those at the European- or country-level for 2030 or 2035) and can reduce the financial burden on government support schemes funded by all consumers. Additional benefits from corporate PPAs can occur if DCs make their sites available for renewables, or if DC owner support is influential in advancing planning applications for new wind and solar facilities.[76]

VRE roll out rates are projected to be very high across Europe (see Chyong et al., 2021) and it is unclear what the role of PPAs is in increasing the rollout rate or in reducing the price, given that such PPAs will cover significantly less than the total requirement (up to 78% of all electricity is VRE in 2050 in Chyong et al., 2021). Constraints to the achievement of very high levels of VRE are unlikely to be contractual. Indeed, in Ireland there are doubts about the ability to deliver much more additional VRE capacity, regardless of new corporate PPAs.[77]

The increased integration between European markets that is envisaged may also mean that, on average, wholesale power prices will be more similar between European power prices than they are now, and that lower average prices in parts of Scandinavia will be more similar to mainland Europe.

4.5.2.2 In heating

Heat decarbonisation presents a significant challenge for Europe. While electricity demand will rise under net zero due to increased electrification and there is the prospect of continuing technological progress on VRE electricity generation costs, the near term decarbonisation of heat seems certain to raise heating costs substantially. This is because natural gas-based heating is a very cheap source of heat. Electrification, use of hydrogen, biomethane or synthetic fuels represents a sharp increase in cost.

The replacement of gas boilers with electric heat pumps or with hydrogen boilers will be expensive and potentially disruptive. Biomethane and synthetic methane in existing gas networks would be less disruptive but the zero carbon methane will be substantially more expensive – as we discuss below - and it is by no means clear that enough of this methane is available to meet the potential demand.

For commercial buildings, such as DCs, who produce reliable heat in the winter, this may present an opportunity. Unit heat prices should rise substantially, and hence if waste heat can be captured for use by nearby heat loads, the economic viability of local heat schemes should improve. However the extent to which governments will be willing to allow prices to rise for heating will be a key political test for net zero. Heat network economics are challenging at the best of times, but rising energy efficiency and reductions in the volume requirements for heating also raise the unit network capital cost for district heating schemes.[78]

4.5.2.3 In transport

Net zero modelling for Europe shows heavy electrification of passenger cars, vans and public transport (European Comission, 2018). This has major implications for the electricity system, not so much in terms of electricity demand but in terms of the flexibility of the electricity system. Electric

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[76] The role of DC owners in supportive renewable power is discussed in Kao (2015).
[77] Cornwall Insight, see: https://www.cornwall-insight.ie/publications/sem-chart-of-the-week/corporate-ppas-signed-sealed-delivered/?filter_year=2019
[78] Some of the challenges behind district heating scheme financing are discussed in Kelly and Pollitt (2011).

vehicles are energy efficient relative to combustion engine vehicles and their efficiency can be expected to increase over time as they are fully re-optimised for a largely electric transport system with the average vehicle becoming lighter and using even less energy. For instance, widespread use of electric scooters and bikes could further significantly reduce energy use.

Electric vehicles represent a challenge and opportunity in terms of the timing and location of their charging. Electric vehicles (certainly initially) will have a lot of on-board battery capacity. This can either draw a lot of power from the grid or supply a lot of power to the grid. In terms of challenge, peak demand from the electric vehicle (EV) fleet for Great Britain could add 6.9 GW to total winter peak electricity demand (currently around 50 GW by 2030),[79] however this would be much higher (almost 10 GW) if this was via uncontrolled charging which did provide any quantity or price signals to when EVs could charge. The problem can be even more significant at individual substations within the electricity grid, where at the street level demand could be 40% higher with uncontrolled charging (Aunedi et al., 2015).

However the opportunity is also large. Plugged-in EVs could absorb or supply significant amounts of VRE electricity to support the grid. If 10% of 30 million vehicles (in GB) were available with a 7kW connection, this would represent 21 GW of flexible capacity (up or down). Thus the smart charging potential in transport is enormous. The ability to exploit this flexibility will require significant amounts of real time data processing, including communication directly to the electric vehicles. This is a key energy IoT application into the 2030s.

4.5.3 Climate change and extreme weather

We are seeing accumulating evidence that climate change is associated with increased variance in weather patterns. This manifests itself in increased deviation from long run average temperatures. Econometric analysis shows that this is not just a problem for agricultural sectors, but for the entire modern economy (Kahn et al., 2019). This is because just-in-time supply chains are badly affected by temperature variations in either direction (both extreme heat or extreme cold). The recent Texas blackout in February 2021 was an example of the impact of extreme cold, while the recent heat wave on the Pacific north west of North America in July 2021 is an example of extreme heat.[80] These events impact the electricity (and gas) systems directly as well as buildings (some infrastructure was being hosed down with water to prevent overheating in the July 2021 event) and general logistics of a modern economy (such as staff travel to work and the movement of spare parts).

The climate modelling says that these events will become more frequent as climate change raises average global temperatures. The negative GDP impact is, if anything, larger in richer more networked economies (Kahn et al., 2019). Lots of associated investments to mitigate risks will be required, such as moving energy facilities to higher ground (to reduce flood risk) or increased use of undergrounding of energy networks. These will add directly to energy system costs as well as produce additional costs for operators of energy intensive equipment (Forzeri et al., 2018). These climate events interact with net zero policies. Climate events will likely spur public pressure to move forward with net zero investments and will also require increased investment to make VRE more resilient to extreme weather. Extreme winds or prolonged wind lulls reduce wind turbine outputs, while extreme heat is bad for electricity network efficiency (losses rise) and for the efficiency of solar panels.

DC owners and operators might be one of the sectors that needs to think carefully about this actual impact of climate change (Durairajan et al., 2018). DCs benefit from cooler locations with low long term weather variability in Europe. DC strategists might also reflect on the impact on both IT demand

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[79] See: NG ESO (2021, FL.11).
[80] See: https://www.theguardian.com/commentisfree/2021/jun/30/canada-temperatures-limits-human-climate-emergency-earth

and on their ability to meet it at particular locations in the face of increased average temperature and increased temperature variance.

4.5.4 Carbon pricing and energy pricing

Net zero will likely significantly raise the unit price of energy. It has to, if relative total energy demand is to fall in line with the modelling (e.g., in Chyong et al., 2021). A reduction in energy demand of 33% requires a rough increase of two thirds in the price of energy, at a price elasticity for energy of 0.5,[81] more if income grows or the elasticity is less In doing so it will also change relative prices within the economy substantially, as we suggest below.

How much prices will change for end-consumers of energy is difficult to identify with clarity. This is because of energy taxation, the impact of subsidies and the way network-fixed costs are recovered from energy consumers. Energy taxation on fossil fuels for surface transport is significant in Europe (fuel duties are large), moderate on electricity (VAT + carbon prices) and generally very low on natural gas for heating.[82] Renewable and energy efficiency subsidy charges raise the average price of electricity, but not so much for natural gas, while there are significant energy efficiency and bill reduction rebates for a significant minority of electricity and gas customers. Network-fixed costs are recovered from different sizes of connection largely via per unit charges which are not differentiated by location within network company areas.

There is lot of hope that renewables production costs will continue to fall (Newbery, 2018), as will the cost of batteries and electric vehicles (Newbery and Strbac, 2016). Currently these remain relatively expensive (relative to fossil fuel-based electricity and transport), but they are getting cheaper. However average prices of electricity are rising even as renewables costs fall due to rising network costs, rising carbon costs and increased renewables costs. It seems likely that underlying costs in electricity will rise modestly. However, final electricity costs will be driven by the need to back-up renewables with storage and with much larger electricity networks, against a backdrop of only moderate increases in overall demand.

In heating, we start from the position that gas consumers face very low additional taxes and the alternatives to natural gas are all substantially more expensive both in unit cost and in terms of the customer capital investment required.

In transport, while the unit cost of surface transport might fall substantially due to electrification, air transport (and other types of heavy duty long-distance transport is quite another matter). Here biofuel, synthetic fuel and hydrogen are all expensive alternatives, even if we ignore the fact that vehicles which might use them do not currently exist (e.g., hydrogen planes).

A simple way to think about the pricing impact of net zero is to make use of the assumption (in Chyong et al., 2021) that the carbon price could be €350 per tonne in 2050 (in current Euros) and that the current price is €50 per tonne. Assuming that some use of fossil fuel remains even in net zero, this sets the price (or willingness to pay) for alternative zero carbon technologies.

Assume that the price of electricity is currently €125 per MWh for non-households and €210 per MWh for households[83]; the price of gas is €28 per MWh for non-households and €70 per MWh for households[84]; and the price of aviation fuel is €32 per MWh of fuel.[85]

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[81] For estimates of long run energy price elasticities for the UK. See: Fouguet (2014).
[82] See: Pollitt and Dolphin (2020) for a discussion.
[83] Data available from Eurostat: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics
[84] Data available from Eurostat: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_price_statistics
[85] For Jet A-1 fuel.

At 0.36 tonnes of CO_2 per MWh, a very efficient gas-fired power plant would be €106 / MWh (0.36*300) more expensive in net zero, or around 90% more expensive for non-households and 50% higher for households.

Direct combustion of methane releases 0.202 tonnes of CO_2 per MWh of gas, but gas is not exposed to CO_2 pricing at the moment in most European countries, so it would be €71 / MWh (0.202*350) more expensive, or around 250% more expensive for non-households and 100% higher for households.

Aviation fuel is currently untaxed and releases 0.252 tonnes of CO_2 per MWh, so this would be €88 / MWh (0.252*350) more expensive, or 275% more expensive.

It is important to say that this overstates the likely relative price rise in electricity which is the only one of the three major sectors where complete decoupling from fossil fuel + carbon prices seems achievable, with no use of fossil fuels in the system. If this occurs, lower VRE-related costs could negate the need for real price rises to 2050 (though storage and network costs could still be cost drivers). By contrast net zero modelling assumes that some (limited) fossil fuel is likely to still be used in heating and transport in 2050.

All this suggests that electricity-consuming devices might see the least relative energy cost rise. They also offer the highest potential for end-to-end increases in energy efficiency. Heat, where there is least opportunity for rapid innovation, sees substantial cost rises.

Meanwhile within transport there will be large rises in some transportation system costs. Assuming a 350 Euro per tonne of CO_2 price, the fuel-related cost of flying across the Atlantic from London to New York return will rise from €104 at present to €390.[86] To put this in context the EV cost per mile is only 6.93c/mile in 2050,[87] while the fossil fuel cost per mile in GB is current 18c/mile in 2021.[88] So one could imagine large potential increases in short distance transport relative to long distance transport.

These price differences will have substantial impacts across the whole economy on relative costs of different types of energy-related activities and on end-to-end costs of energy intensive versus energy non-intensive economic activity.

Rising absolute energy prices and changes in relative energy costs could have profound impacts on the structure of the economy and on the use of data and hence the demand for DCs. Long distance travel seems set to be much more expensive under net zero relative to what it is now. So even if DC electricity costs rise, rising energy costs seem set to be good for promoting the use of data, for instance in video conferencing as an alternative to travel. Energy costs will rise in every area of energy consumption promoting the substitution of data for energy, via smarter use of energy in transport, heating and power.[89]

4.5.5 Locational pricing and charging within the electricity transmission and distribution system

There is already a trend towards more use of prices to signal location within the electricity system among leading jurisdictions (Pollitt and Anaya, 2016). This has been in spite of the EU attempting to encourage uniform wholesale electricity prices.

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[86] See: https://www.flightdeckfriend.com/ask-a-pilot/how-much-fuel-does-a-jumbo-jet-burn/
[87] Electricity price = 125 + 106 Euro per MWh; EV uses 300 W per mile.
[88] See: https://www.nimblefins.co.uk/average-cost-petrol-car#mileage and assuming 1.15 Euro = £1.
[89] Historically such changes have had big effects on the economy. Allen (2009) discusses how large differences in relative energy prices between countries promoted the industrial revolution in Britain.

Net zero however suggests two important things for variations in electricity prices across Europe. First of all, an extreme VRE-based electricity system promotes the integration of European electricity markets, and this reduces average wholesale price differences between areas (Chyong and Pollitt, 2018; Chyong, 2021). For instance, if interconnection between Scandinavia and Central Europe significantly increased, substantially prices would be more equal more of the time, even with the existing EUPHEMIA algorithm which allowed zonal prices at times of binding transmission constraints between zones. Second, VRE will create more local, seasonal and daily variation in underlying costs of serving particular locations. This will either show up in more use of prices to ration quantity or increases in the ability to get paid for being flexible (which amounts to the same thing). If this is not allowed to happen, costs will go up for all customers, as higher-cost alternatives to securing the system such as overbuilding back-up generation, storage or network capacity have to be enacted. Given that many domestic consumers might have to be protected from rising costs, these costs will likely fall on commercial customers with higher ability to pay, as they have done historically (Peltzman, 1976).

Locational charging is not just about wholesale energy prices varying by location. It can also be about connection costs and use of system charges for networks. Connection charges normally only reflect the cost of the direct use assets required to physically connect a new load to the existing network. The direct use asset costs are the 'shallow' costs of connection. However connection costs can be 'deeper' in the sense that they can involve more or less of a contribution to the wider costs of reinforcing a network to connect a large new generator or load. Distributed generators in Great Britain have to pay 'shallowish' connection costs where they make a contribution to the wider network reinforcement costs (if they want a fixed capacity availability guarantee).

'Deeper' connection charging could involve a new large load contributing to the costs of upgrading substations or lines in the wider network not just for direct use. Use of system charges can also reflect the costs of connecting larger loads to the network at certain locations. For instance, in Great Britain there are 14 demand charging zones for transmission use of system charges, with the North of Scotland being the lowest and London being the highest. These annual charges for transmission are charged to loads based on their MW load at the measured system peak. In 2021/22 this makes almost a £4m cost difference to a 100MW peak load.[90] Going forward, there continue to be increasingly strong arguments for more cost reflectivity in connection and use of system charges within countries to direct loads to locations where whole system costs are lower.

It seems likely that DCs will need to think more carefully about where they are locating within the electricity grid, and about what impact they might be having on total energy system costs, given that they will bear these in at least proportion to their share of the load. The clustering of DCs around electrically congested areas, with emerging VRE supply constraints is something that will either raise electricity costs substantially or result in an increased willingness on the part of local and national governments to prevent new investment going ahead in electrically constrained areas.

4.5.6 Local energy markets, flexibility and energy communities

The wide area picture for the energy system in general and the electricity system in particular under net zero has been sketched above. However, it is worth thinking further about what this might look like in particular locations.

The more active distribution system operator is something that the European Commission has been seeking to encourage (Pollitt et al., 2021). It has been promoting the use of competitive mechanisms to procure constraint management and voltage support services. These are procured to manage electricity demand at specific points within the distribution system and can involve paying loads or

[90] The difference in charge is almost £40/kW. See: https://www.nationalgrideso.com/document/176886/download

generators to be more flexible. Experiments are taking place in competitive procurement of such flexibility, effectively leading to local pricing of electricity servicers, by use of local market platforms (such as GoPACs or Piclo Flex) (Anaya and Pollitt, 2020). The European Commission has also been promoting energy communities, which are groups of final consumers who actively manage their interconnection with the main grid and are encouraged to self-balance and benefit from reducing their wider grid impacts.[91] Such communities might have their own generation and storage and the ability to operate in island mode. They can then benefit from reduced network charges and more (or less) exposure to wholesale electricity price fluctuations. Such communities could involve an anchor load/generator.

Large loads, such as DCs, in the distribution system could potentially benefit from both of these trends, as they are about empowering smaller consumers and generators to participate more actively in the lower carbon electricity system. This is about smart grid-responsive DCs which contribute to supporting the stability of grid for the generality of users (Ghatikar et al.,2015. Thus, partnering with local communities in exploiting community demand response or community generation or community storage assets could be a potential opportunity for the mitigation of electricity costs and good corporate citizenship (Wahlroos et al., 2018). This could be an obligation placed on all new loads above a certain size.

An important issue in a more flexible electricity system is the need for increased visibility and predictability of individual distributed loads and generators. Traditionally, the transmission-level system operator has only been able to directly monitor the electrical injections and withdrawals of large generating units and large interruptible loads. There has been much less visibility at lower voltages and still less ability to predict usage patterns with a view to managing a constrained distribution system in real time. Over time, we would expect much more monitoring of individual loads consumption profiles and incentives to provide information on drivers of demand and the condition behind the meter batteries and onsite generation. This has implications for DCs, as well as other loads with UPS and onsite generation capability.

4.6 Closing thoughts on the development of DCs within the energy system in Europe

Overall, it seems clear that DCs will face a changing general net zero policy environment. This will involve rising electricity prices and local grid connection costs at congested locations. DCs that can be flexible in their power usage and provide heat to their localities will have relatively lower costs.

The Irish and Danish case studies show that some DC cluster locations are already adapting better than others to implications of net zero. Denmark is heavily interconnected, has well-developed local heat networks and has an increasingly carbon-free electrical electricity system. Ireland is poorly interconnected and without intervention is predicted to struggle to combine decarbonisation with rising electricity demand (see CRU, 2021). Ireland is clearly a candidate for better use of local transmission and distribution price signals to better reflect grid connection costs and more innovation with respect to the use of DC heat. In Ireland there is a need to develop more VRE capacity – possibly in the form of offshore wind – or increased interconnection.

Extra electricity demand, which increases the requirement for both intermittent renewables and associated reserve capacity, potentially increases the problem of getting to net zero in a given jurisdiction. Reserve capacity is relatively expensive for small electricity systems with expensive interconnection costs. The Irish example illustrates that rising demand, in this case from DCs, puts

[91] For more details on energy communities see: https://ec.europa.eu/energy/topics/markets-and-consumers/energy-communities_en

additional pressure on the need to find new renewable sites, acquire back-up and increase interconnection at the national level. To the extent that these costs are not fully reflected back on to the sources of increasing demand, this raises costs for other electricity users.

The Irish and Danish case studies, together with the general requirements for net zero, indicate that there may be a need, in the future, for all new large loads above a certain size to face stronger financial incentives which reflect whole system expansion costs, and hence incentivize their flexibility, providing incentives for investments in UPS, batteries and supplementary power sources either on- or off-site.

05

REGULATORY ISSUES AND PROPOSALS

5 Regulatory Issues and Proposals

This part of the report aims first to advise on which regulatory approach the EU should pursue when considering the evolution of DCs (5.1). This is accompanied by a reflection on the possible role model DCs can be for the regulation of energy intensive industries in general (5.2). It then reviews specific areas of EU intervention, both existing EU environmental (5.3) and energy (5.4, 5.5) legislation and proposals for new rules with relevance for the future development of DCs. Recommendations are made as to how to further improve the current regime and the proposals put forward as part of the European Green Deal Strategy and the 'Fit for 55 package'.

5.1 Regulatory approach

In terms of regulatory approach, it is important to remember that any legislative proposal put forward by the European Commission is subject to the principles of subsidiarity and proportionality. It must also have a clear legal basis in European Treaties. Any legislative proposal must also be in accordance with the repartition of competence between the EU and its Member States. Such repartition of competence will vary according to the area of intervention, e.g., between energy or environmental policy (shared competence) and taxation policy (direct competence is an exclusive competence of the Member States, harmonised taxation rules subject to unanimity).

The DC industry is developing very quickly and in parallel with the associated digital services when it comes to regulation. In both sectors, innovation is crucial and must continue to be encouraged, while safety, reliability and environmental protection considerations would benefit from a minimum degree of legislative harmonisation. Not least, a level playing field will preserve the functioning of the internal market for the services and products provided by DCs. This argues in favour of a 'dynamic regulatory approach',[92] based on a combination of legislation, standards, soft law/guidance instruments and self-regulation. Such an approach is also favoured by CEER in its most recent positions, and may go further than the currently applicable legislation to DCs.

As underlined above in Section 3, EU intervention may be justified by the need to provide a level playing field among Member States for the development of DCs and related services and products. Therefore, some minimum common definitions, principles and obligations and operating rules should be enshrined into EU law.

To sum up, when advancing regulatory proposals on DCs, a dynamic regulatory approach should be favoured, based on a mix of legal instruments (legislation, guidance, standards, self-regulation), of both legally binding and non-legally binding nature. This will preserve the objectives of both the internal market and environmental protection, but also provide sufficient flexibility to enable the sector to develop further, in an iterative way.

EU regulatory intervention should prioritise the harmonisation of common definitions, principles, and obligations and operating rules enabling DCs to develop under climate neutrality objectives and an increasingly integrated energy system. EU regulators should also prioritise sectors with the highest potential impact, such as public entities.

Even if DCs are not singled out in regulation they may be subject to the increased regulatory scrutiny that will apply to all large loads under a net zero energy policy. There will be pressure on larger loads to be subject to real time monitoring and control in line with the need to manage VRE output. This, in turn, will require more information to be given about an individual DC's capacity for flexibility, both in terms of equipment and underlying use drivers. One can imagine that grid connection rules

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[92] For more details on dynamic regulation see: https://www.ceer.eu/dynamic-regulation

and national regulation will be altered to encourage better provision of real time information and amenability to energy demand modelling. This can surely be done without compromising underlying DC user data, but it may have implications for the privacy of DC owner data volume information at the individual DC level.

5.2 DCs: possible role model for the regulation of energy-intensive industries

Because of the characteristics and types of services/products that DCs deliver, there is a need to align their regime with other energy intensive industries. This requires investigating and comparing the types of obligation, but also incentives (both regulatory and financial), that energy intensive industries benefit from. In that context, a minimum harmonised approach at the EU level should be prioritised, in order to preserve the internal market and competition between Member States.

As part of the alignment of regimes across the energy and telecommunications sector, and keeping in mind security and resilience imperatives, one should **follow carefully the proposal for a new directive on measures for a high common level of cybersecurity across the Union that will repeal the current NIS Directive (EU) 2016/1148 on security of networks and information systems (European Commission, 2020f). Consistency should also be kept with the European Critical Infrastructure Directive (see Section 3.1.3 above)**. Notably, *a priori* not all DCs need be defined as 'critical entities'. In reality, networks of DCs may involve a degree of redundancy which means that though the network is critical, any given DC may not be, and does not need to be designated as such.

5.3 Emissions control from DC activities

As previously explained, climate neutrality objectives and net zero commitments are driving the binding or voluntary regulatory initiatives in the DC industry. At EU level, the climate neutrality objective enshrined in the European Climate Law needs to be followed up with concrete actions by the EU institutions and Member States, of the type discussed in the previous section. Therefore, the European Commission has already announced a series of new initiatives aimed at reducing GHG emissions from DCs, but also to ensure a circular approach to natural resources and increased integration of the energy system around DCs. These new initiatives build upon pre-existing legislation on ecodesign and energy efficiency, which both are up for revision.

5.3.1 Planning requirements

At the upper level, the role of DCs is increasingly reflected in planning documents for both (i) climate and energy system (e.g., in NECPs as part of the Energy Governance mechanism, or national Energy Efficiency Plans) and (ii) energy infrastructures (e.g., as part of the ENTSO-E Ten Year Development Plan). **The integration of DCs into high-level energy planning processes should be further extended.** This should also be coordinated with land and city planning processes. This necessary integration of DCs and coordination between planning processes would enable DCs to achieve cost-efficiency, resource-efficiency and better coordination and local acceptance. Synergies across sectors and activities could be identified early. This could ensure that DCs do not create unnecessary demand for connection capacity and do not add costs for resource adequacy to other electricity consumers.

5.3.2 Ecodesign requirements

Several EU legislative acts define ecodesign requirements for ICT products. Notably, Regulation (EU) 2019/424 lays down ecodesign requirements for servers and data storage products.[93] The scope of

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

application of the Regulation will depend on the type and size of the servers and products. This regulation establishes ecodesign requirements for placing servers and online data storage products on the market and putting them into service, and is therefore relevant to the regulation of DCs. It aims to curb energy consumption of electronic devices and groups different types of products into different 'Lots', with Lot 9 assigned to servers and storage equipment. While the Regulation covers products that are relevant to DCs, it does not cover the entirety and complexity of modern DCs.

The Ecodesign Directive thus provides a useful legal basis for the further regulation of energy consumption by DCs. Notably, it could be used to reflect some of the (voluntary) adopted standards where there is a need for further harmonisation. It can also be used and possibly amended to include modern DCs entities.

5.3.3 Energy efficiency requirements

Energy efficiency (EE) in DCs has been an area of voluntary cooperation between actors in the sector. This resulted in the adoption of the European Code of Conduct for Data Centres in 2008. The Code of Conduct is a voluntary initiative, managed by the JRC, which sets ambitious voluntary industry standards for companies willing to participate (called Participants). The Code of Conduct identifies and focuses on key issues and agreed solutions, described in the Best Practices document (JRC, 2021). In addition to the participants, companies (vendors, consultants, industry associations) can also promote the Code of Conduct to their clients. This is in line with an increased focus on supply chain commitments at EU level. The participants that significantly reduce their energy consumption are eligible for the annual EU Data Centres Code of Conduct Awards. **As a possible improvement, these voluntary efforts could be harmonised with the Climate Neutral DC Pact. There is a need for streamlining the different initiatives and certification schemes that have flourished in the market.**

On top of these voluntary industry standards, the European Commission has promoted the **'Energy Efficiency first (E1st) principle'** as one of the cornerstones of the European Green Deal. Article 2 (18) of the Governance Regulation provides for the following definition of the E1st Principle: "*taking utmost account in energy planning, and in policy and investment decisions, of alternative cost-efficient energy efficiency measures to make energy demand and energy supply more efficient, in particular by means of cost-effective end-use energy savings, demand response initiatives and more efficient conversion, transmission and distribution of energy, whilst still achieving the objectives of those decisions*."

The European approach of E1st aims for a broader scope encompassing **the entire energy system**. This calls for a transversal approach throughout the energy system, and therefore current legal frameworks must be revised accordingly. The E1st principle is in line with net zero modelling discussed in the previous section which suggests that net zero requires a large reduction in energy usage in Europe relative to business as usual of around one third.

The next step for the European Commission, as part of the 'Fit for 55' Package, is to implement this principle into concrete legal provisions, such as:

- Giving priority to demand-side solutions in general whenever they are more cost effective than investments in energy supply infrastructure;
- Properly factoring energy efficiency in generation adequacy assessments;
- Extending incentives under the Energy Efficiency Directive (EED) and the Energy Performance and Building Directive (EPBD) (now mostly for customers) to the full supply chain;
- Consumer information reflecting the life cycle energy use and footprint of the different energy carriers, including natural resources use;

- Investments in EE solutions: sustainable finance (e.g., taxonomy regulation and screening criteria).

For DCs, there will be consequences, one of which will be that emphasis is put on the use of local energy sources in buildings and communities and 'energy re-use'. The principle of circularity is in line with the new Circular Economy Action Plan, which prioritises the reuse of waste heat from industrial sites, DCs, or other sources. Such requirements are partly covered by the EED and the Renewable Energy Directive (REDII), but the Circular Economy Action Plan implies further initiatives on information requirements, regulatory and contractual frameworks to share the costs and benefits of new investments, and removal of barriers related to planning, transaction costs, and pricing signals. Finally, when implementing the E1st principle, EU authorities should understand and appreciate the trade-offs to be made in terms of processes and achieved energy efficiency. For example, heat recovery leads to greater power consumption at the DC and therefore impacts energy efficiency gains or losses. Likewise, greater focus on water conservation increases energy consumption. This may call for a higher emphasis on life-cycle assessment requirements in that context and the use of a wider range of measures of energy efficiency, as discussed in Section 2.3. Ultimately, this can result in a call for a greater shift to the cloud, based on energy efficiency gains and need to reduce GHG emissions. Such a move has already been advised by the Department for Business, Energy and Industrial Strategy (BEIS) in the UK as part of their recommendations to businesses to reduce their carbon footprint by 2030. The BEIS is notably recommending to businesses to move more of their on-premise IT infrastructures to the public cloud instead of housing it within their own private data centers.[94]

As part of the 'Fit for 55' package, the European Commission has already made several proposals for revision of the Energy Efficiency Directive targeting DCs (European Commission, 2020c). The newly proposed Article 11 introduces an obligation for the monitoring of DCs' energy performance with the aim of later establishing a set of 'data centre sustainability indicators'. The objective pursued by the introduction of such indicators is further explained in the draft recital (66)-(67):

> "(66)***To promote sustainable development in the ICT sector, particularly of data centres, Member States should collect and publish data, which is relevant for the energy performance and water footprint of data centres [emphasis added].*** *Member States should collect and publish data only about data centres with a significant footprint, for which appropriate design or efficiency interventions, for new or existing installations respectively, can result in a considerable reduction of the energy and water consumption or in the reuse of waste heat in nearby facilities and heat networks. A data centre sustainability indicator can be established on the basis of that data collected*."
>
> (67**) *The data centre sustainability indicators can be used to measure four basic dimensions of a sustainable data centre [emphasis added],*** *namely how efficiently it uses energy, how much of that energy comes from renewable energy sources, the reuse of any waste heat that it produces and the usage of freshwater. The data centre sustainability indicators should raise awareness amongst data centre owners and operators, manufactures of equipment, developers of software and services, users of data centre services at all levels as well as entities and organisations that deploy, use or procure cloud and data centre services. It should also give confidence about the actual improvements following efforts and measures to increase the sustainability in new or existing data centres. Finally, it should be used as a basis for transparent and evidence-based planning and decision-making. Use of the data centre sustainability indicators*

[94] UK - SME Climate hub: https://smeclimatehub.org/uk/

should be optional for Member States. Use of the data centre sustainability indicator should be optional for Member States."

The proposed recast of Article 14 (waste heat) will also target DCs with a view to achieving higher energy system integration (use of waste heat, electrical and thermal efficiencies), but also local planning and development. Surplus heat from DCs should be used in relation to district heating and cooling. This will reinforce the requirements for efficient district heating and cooling. **According to the proposal, all district heating and cooling systems should aim to improve their ability to interact with other parts of the energy system in order to optimise the use of energy and prevent energy waste by using the full potential of buildings to store heat or cold, including the excess heat from service facilities and nearby DCs.**

Further, new provisions concerning DC energy consumption and sustainability rating have been proposed in Article 24 (**Heating and cooling supply**), Article 31 (Delegated acts and the introduction of **a common Union scheme for rating the sustainability of DCs located on Union's territory**), as well as in Annex VI (**Minimum Requirements for Monitoring and Publishing the Energy Performance of Data Centers**).

5.3.4 Public procurement criteria for DCs

The JRC has developed EU Green Public Procurement (GPP) criteria for Data Centres, Server Rooms and Cloud Services (JRC, 2020). The EU GPP criteria aim at facilitating public authorities' purchase of products, services and works with reduced environmental impacts. The use of the criteria is voluntary. The criteria are formulated in such a way that they can be integrated into the individual authority's tender documents, if deemed appropriate. The JRC document provides the EU GPP criteria developed for the product group 'Data Centres and Server Rooms'. **This implies that government data should make use of greener DCs.**

There are four main types of GPP criteria: Selection Criteria (SC); Technical Specifications; Award criteria; Contract Performance Clauses (CPC). For each set of criteria there is a choice between two ambition levels:

1. The core criteria are designed to allow for easy application of GPP, focusing on the key area(s) of environmental performance of a product and aimed at keeping administrative costs for companies to a minimum.
2. The comprehensive criteria take into account more aspects or higher levels of environmental performance, for use by authorities that want to go further in supporting environmental and innovation goals.

<u>Areas of improvement of the regulatory framework include:</u>

1. Generally, due to their purchasing power, public entities should have a stronger focus on making use of greener DCs. There is a huge potential for more energy efficient use of data in public sectors, as these are often old and therefore less energy efficient.

2. The recommendation would be to further commit public authorities and publicly owned entities to rely on the EU GPP criteria. They should also consider joining the Code of Conduct of the Climate Neutral Pact.

3. Further, public entities should consider and assess a possible shift from on-premises/enterprise DC to the cloud. Such a shift could result in significant energy savings and could be encouraged by a regulatory incentive to at least assess a possible shift (e.g., a mandatory requirement to assess a possible shift).

5.4 Grid connection rules

5.4.1 Connection configuration

Most DCs rely on a double connection to the grid, one working cable and one back-up cable. The two cables are connected either to one single source or two separate sources (Loeffler and Spears, 2015). This provides a more secure electricity supply and a back-up solution in case of default.

5.4.2 Connection terms

Due to the particular load that DCs represent, connection rules may be adapted according to the qualification of the DCs.

As mentioned previously, DCs may connect at different grid levels, depending on the size of the centre. While small DCs (e.g., with a power demand of approximately 10 MW or less) can connect to the distribution grid (depending on where the transmission/distribution boundary is defined), bigger DCs may be connected directly to the overhead grid at transmission level. Depending on the alternative chosen, the connection may trigger investments at either the transmission or distribution level.

The connection and ownership model for DCs differs among countries, with different recommendations from the national regulatory authorities. For example in Norway, the regulator recommends grid companies to be the licence holder and owner of the grid connection from the DC to the grid (NVE, 2018). In the UK, DCs may bear a greater share of deeper grid reinforcement costs.

A question, which could be subject to further harmonisation at the EU level, relates to whether DCs – as similar large energy users - could benefit from a specific regime for connection to the grid. Under the Electricity Directive, Distribution System Operators (DSOs) and Transmission System Operators (TSOs) are obligated to offer all customers a grid connection. This obligation can extend to planning obligations and investment in new capacity without any unfounded delay to fulfil the connection obligation. However, this obligation is conditioned by the customer’s willingness to pay the connection charge and grid tariffs (which may include wider grid reinforcement costs) and their options for making onsite electricity generation and storage investments which would achieve their required electrical reliability standards. In terms of load management, another path would be to further rely on locational pricing on the transmission system as a way to encourage further distribution of, e.g., DCs. This approach does not need to single out DCs, and a common approach for large energy users is recommended (see Section 5.2 above).

Finally, sharing good practices in terms of grid connection agreements for DCs, among other large energy users, would contribute to ensuring a level playing field among grid users and a foreseeable grid management for grid operators. As the DC sector develops, flexible connection arrangements may be necessary, together with price signals which more correctly reflect system costs as they develop. That could encourage data centers to e.g., invest in back-up generation and the ability to react to grid condition. Flexibility should be accompanied by foreseeability and emphasis should also be put in connection agreements on the need to ensure transparent and good information exchange between grid companies and DCs on upcoming connection needs and possible scale up of activities.

5.5 Financial incentives

5.5.1 Revision of the Energy Taxation Directive

In the framework of the ‘Fit for 55’ climate package, the European Commission foresees a revision of the Energy Taxation Directive that will also impact DCs.

Currently, DCs benefit from different special provisions – such as a reduced rate of electricity tax – in some countries. In Finland, Sweden and Norway, DCs can benefit from a lower business rate (often subject to a threshold limit). In France, DCs can benefit from a reduced tax rate of €12/MWh for the fraction of their annual consumption that exceeds 1 GWh, if their total consumption of electricity equals or exceeds 1 kWh/€ of added value. However, Norway has excluded DCs used for crypto currency from the list of DCs eligible to a reduced rate of electrical power tax.

The revision of the Energy Taxation Directive might be an opportunity for the European Commission to harmonise certain practices, at least in terms of minimum harmonisation. Such energy-related tax exemptions are unsustainable in an environment of rising energy prices for all and where any tax exemption represents an effective subsidy to greater energy use.

5.6 Concluding comments

This section has outlined how a large number of EU energy policies already impact energy consumption by DCs. DCs are explicitly mentioned in several directives as examples of the demand sectors covered by them, or targeted for specific measures with respect to measurement and reporting. This trend seems likely to increase as net zero and the pathway towards it is a high priority for the European Commission. The direction in which legislation is going seems set: DCs will be increasingly challenged on their energy consumption and they will be expected to interact with the rest of the energy system in a way that facilitates wider decarbonisation.

06

CONCLUSIONS

6 Conclusions

ICT has shown remarkable progress with regards to energy efficiency over the last 10 years, such that, in spite of very high internet traffic growth, there has not been much increase overall in DC energy demand. This contradicts earlier concerns in the 2000s of explosive growth in demand. The move to more efficient cloud hyperscale DCs is part of the explanation behind these efficiency gains. A further move to the cloud would reduce aggregate DC consumption across Europe.

Overall, in Europe, DC energy demand is modest but growing at c.3% of aggregate electricity demand. However, it is much larger in some smaller European countries such as Denmark and Ireland.

Over the next 10 years European internet traffic is expected to grow but the consequences for DC electricity demand are uncertain due to the difficulty in predicting when recent trends of increasing efficiency might reach their limit.

Therefore, it is unclear whether there is an issue with the achievement of sustainable energy solutions to rising DC energy demand across Europe.

Like any significant source of electricity demand, DCs will be subject to a range of European and domestic laws and regulations designed to encourage energy efficiency and the switch to clean energy. Thus we have seen requirements on DCs to provide more information on their energy consumption and on third parties, such as district heating networks, to work with loads such as DCs to achieve wider energy policy objectives.

There are emerging issues around some particular cities, such as Dublin, with large and growing DC clusters. This could potentially result in increased cost to consumers if there are increased demands on electricity networks and should resource adequacy gaps emerge – leading to increased capacity market procurement - to serve the anticipated increase in demand from DCs. It has also resulted in planning permission and siting issues due to concerns about the availability of grid connection capacity, as well as political pressure to curtail DC investment in certain locations.

The modelling of DC electricity demand, and what drives it, is poor. **Better metrics of energy performance need to be in more widespread use.** For instance, the industry standard metric, power usage effectiveness (PUE), does not measure the energy efficiency in terms of work done per total unit of energy consumption. Priority must also be given to better reporting and monitoring around the total energy consumption of DCs. Both the EU and the DC industry need to collect and publish more comprehensive data than the current emphasis on voluntary information provision has given rise to. Commitments on both sides to do this in the future are welcome.

Industry associations and industry standard setting bodies can play a key role in promoting best practice on energy consumption and contributing to wider decarbonisation of the DC sector. The JRC's Code of Conduct on DC energy efficiency has been a good example of a voluntary initiative that has been successful in promoting energy reduction. Codes of conduct should be cutting edge in terms of ambition and inclusive of all players. We welcome the recent Climate Neutral Data Centre Pact initiative of the DC industry in Europe and encourage them to be radical in their ambition.

The industry needs to make more information available so that there can be appropriate independent modelling of the end-to-end energy usage process in the use of ICT. The requirement for this to happen will be an essential part of ICT's contribution to achieving net zero in Europe. Pressure to better measure energy consumption is already manifesting within existing and proposed EU legislation and this trend can be expected to continue.

COVID-19 does not seem to raise particular issues, but climate neutrality does. An electricity system in net zero will be required to be much more flexible in matching demand to supply than it is now, due to the increased prevalence of intermittent sources of electricity generation. Owners of DCs will be subject to rising energy and carbon prices, they will face greater incentives to support wider grid flexibility at the local and market levels. They will have opportunities to contribute to the difficult task of heat decarbonisation by recycling waste heat.

There seems little reason to negatively single DCs out in European law. Rather, a key test is whether EU legislation can develop regulatory incentives to encourage large loads to participate in facilitating the energy transition and energy system integration. DCs, with their need to have UPS and opportunities for back-up generation present opportunities to minimise their impacts on the grid and act as providers of wider grid flexibility. The DC industry in Europe can act as a role model in helping the European Union achieve its climate objectives in an increasingly digital economy.

Issues encountered locally when introducing DCs in certain locations emphasise the importance of:

- Long term planning and investment into grid infrastructure where appropriate. This may involve a deeper discussion between grid operators and DC developers;
- Visibility of load growth plans from DCs;
- Interconnection and network charges that fully reflect the system costs associated with new, large loads;
- Locational price signals via use of system charges for transmission and distribution; and
- Adequate price signals to encourage flexibility and the co-location of batteries, generation and loads.

Corporate citizenship on the part of DC owners requires additional efforts on:

- Better transparency on energy use drivers;
- The widespread use of more accurate measures of end-to-end energy efficiency (not PUE);
- The sourcing of the PPAs in the local energy market where the DC demand is located; and;
- Active participation in local flexibility markets to provide general grid stability support.

It is encouraging to see evidence that DC owners are taking their climate commitments seriously. Nevertheless, the most difficult energy policy issues around DCs in Europe are not at global corporate level, nor are they primarily about financial matching of corporate (or even local subsidiary) supply and demand in real time, with better PPA contracting. They are about their impact on the local grid where DCs are connected, which arises from the interaction between DC demand and the supply and demand balance of other grid users. **Thus the industry, together with electrically similar large loads, can go further in terms of ensuring that large DCs are capable of contributing to system-wide decarbonisation by appropriate configuration of the UPS, onsite back-up generation, energy storage and energy management to increase grid-level flexibility. This remains an under-researched area for future development.**

There is also room for DCs to participate in local heat decarbonisation schemes, renewable energy projects and innovative solutions to wider energy transition issues. **The DC sector has the opportunity to both make a virtue out of facilitating the European energy transition and go beyond the letter of the law and regulation with respect to innovation in energy**

reduction and co-operation with other actors in the energy sector. The requirement for large electrical loads to be good citizens in terms of responding to grid condition is not unique to DCs and hence there is a real opportunity for DC owners to lead by example in doing this. By the same token, locations which are unable to electrically accommodate DCs in Europe in ways which allow DC owners to better meet their public climate commitments will find themselves at a disadvantage in attracting new DC investment.

While DC electricity demand will attract attention given the general need to reduce overall energy use, we must put this in context. The ICT revolution is central to the future of the European economy. Indeed, there is great potential for ICT to contribute to wider decarbonisation via the use of data in energy to reduce energy use generally. The ability of other sectors such as transport to reduce their use of energy will depend on the substitution of data intensive activities for energy-intensive activities, such as the use of video-conferencing instead of international business travel, certainly relative to business as usual.

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APPENDICES

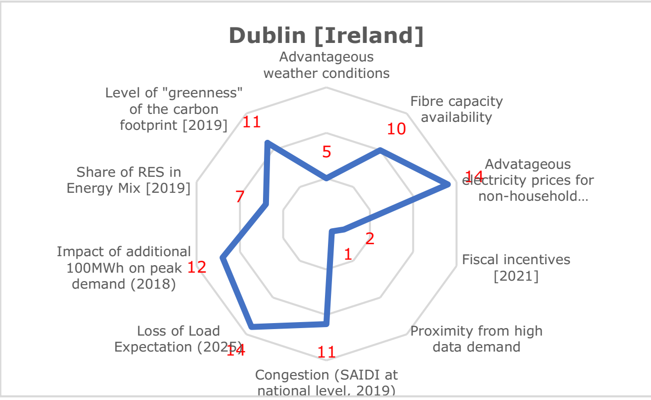
Appendices

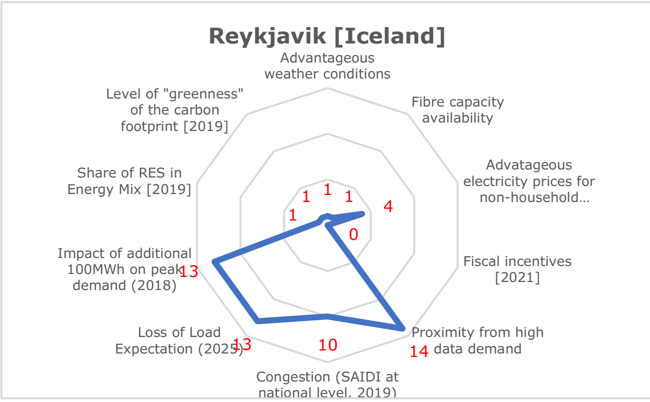
6.1 Annex 1 - A comparison of the attractiveness of different European cities for DC investments

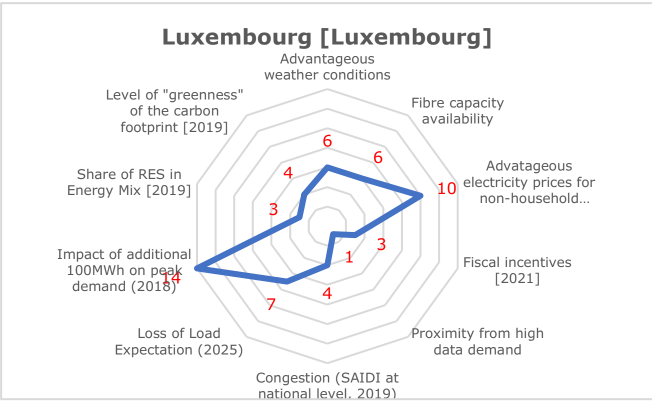
	Advantageous weather conditions	Fibre capacity availability	Advatageous electricity prices for non-household consumers [H1 2020]	Fiscal incentives [2021]	Proximity from high data demand	Electricity grid stability (SAIDI at national level, 2019)	Loss of Load Expectation (2025)	Impact of additional 100MWh on peak demand (2018)	Share of RES in Energy Mix [2019]	National carbon footprint [2019]
[Unit]	*[ºC]*	*[%]*	*[€/KWh]*	*[0-100 score]*	*[km]*	*[hours/ year]*	*[hourd/ year]*	*[%]*	*[%]*	*[gCO₂eq/ kWh]*
Dublin [Ireland]	9.4	7.9	0.126	77	0	0.8	3.35	2.04	37	316
Reykjavik [Iceland]	4.3	65.9	0.071	N/A	1000	0.63	0.27	4.08	99	0
Copenhagen [Denmark]	8.9	24	0.054	56	500	0.5	0	1.65	70	126
Frankfurt [Germany]	10.7	3.3	0.084	58	0	0.25	0.1	0.13	36	338
London [United Kingdom]	10.8	2.8	0.106	69	0	0.28	0	0.16	35	228
Zurich [Switzerland]	9.7	21.3	0.05005	89	0	0.2	0	1.02	58	24
Milan [Italy]	13	4.1	0.085	58	0	1.3	0.1	0.17	35	233
Madrid [Spain]	14.5	54.3	0.078	65	0	0.51	0	0.25	37	207
Lisbon [Portugal]	16.7	42.1	0.079	49	0	0.54	0	1.15	47	244
Stockholm [Sweden]	7.3	56.8	0.064	61	500	0.61	0.1	0.37	61	8
Warsaw [Poland]	9.3	6.5	0.08	46	500	1.13	0	0.41	12	719
Prague [Czech Republic]	9.8	17	0.071	58	500	0.48	0.2	0.90	11	431
Luxembourg [Luxembourg]	9.7	21.4	0.0824	74	0	0.36	0.1	9.70	69	69
EU-27	10.2*	17.1	0.081	63.14	500**	1.01	0.1***	0.00	31	275

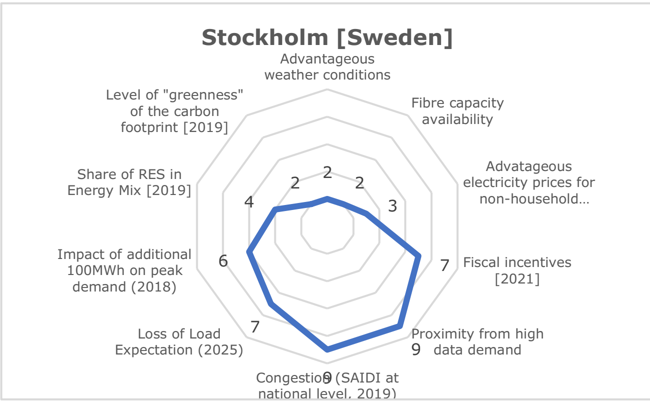
- * Calculated as the average annual temperature for EU-27's capital cities
- ** For comparison, the middle value has been considered as the EU-27 average
- *** Estimated by authors, based on the ENTSO-E's Mid-term Adequacy Forecast.

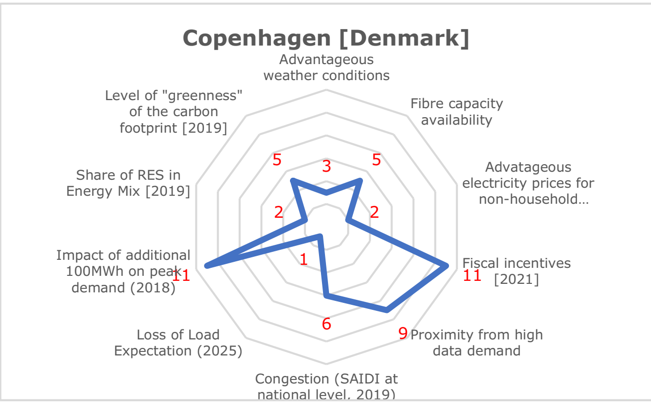
6.2 Annex 2 - Attractiveness of different European cities for DC investments (the higher the ranking, the closer to the graph's centre)

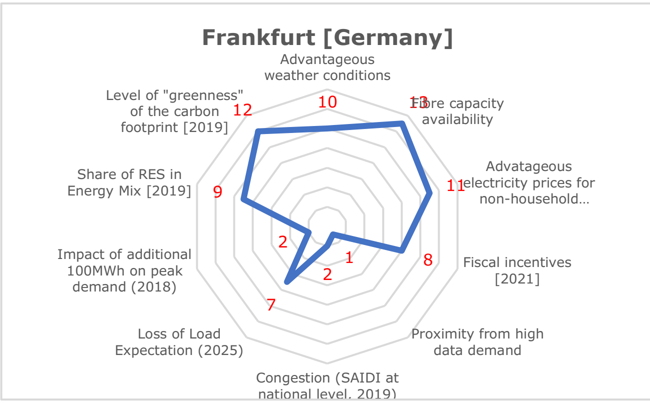


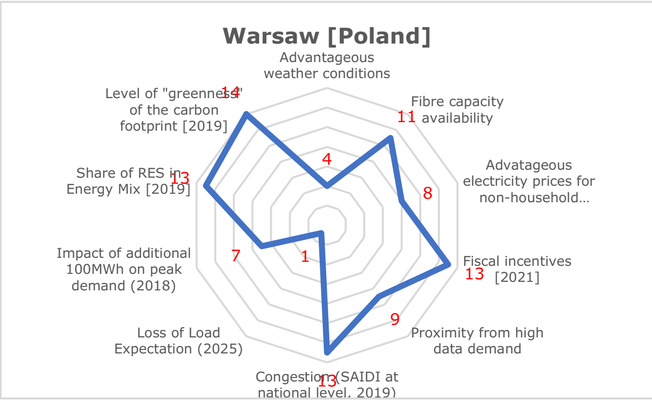


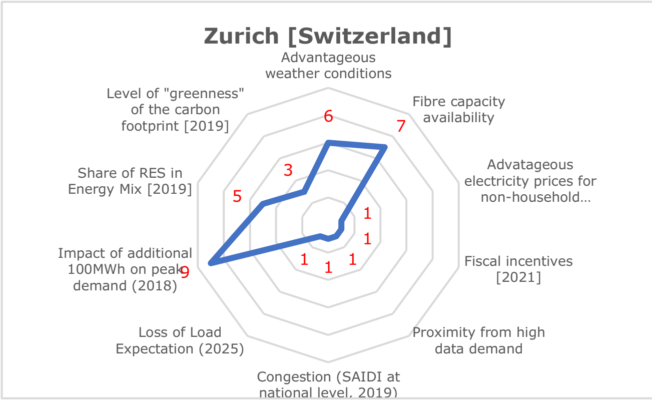


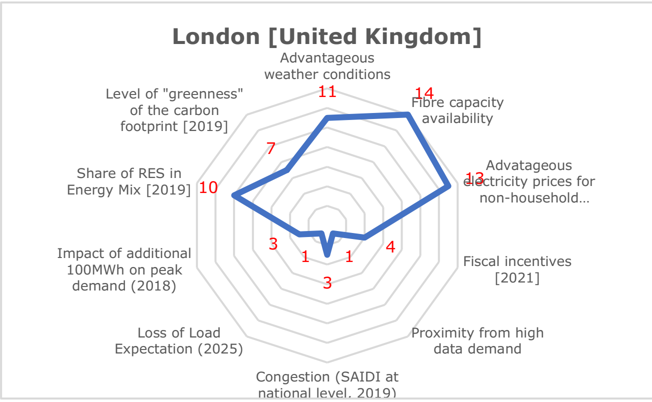







Warsaw [Poland]
Advantageous weather conditions
Fibre capacity availability
Advatageous electricity prices for non-household...
Fiscal incentives [2021]
Proximity from high data demand
Congestion (SAIDI at national level, 2019)
Loss of Load Expectation (2025)
Impact of additional 100MWh on peak demand (2018)
Share of RES in Energy Mix [2019]
Level of "greenness" of the carbon footprint [2019]
4
11
8
13
9
13
1
7
13
14


Zurich [Switzerland]
Advantageous weather conditions
Fibre capacity availability
Advatageous electricity prices for non-household...
Fiscal incentives [2021]
Proximity from high data demand
Congestion (SAIDI at national level, 2019)
Loss of Load Expectation (2025)
Impact of additional 100MWh on peak demand (2018)
Share of RES in Energy Mix [2019]
Level of "greenness" of the carbon footprint [2019]
6
7
1
1
1
1
1
9
5
3


London [United Kingdom]
Advantageous weather conditions
Fibre capacity availability
Advatageous electricity prices for non-household...
Fiscal incentives [2021]
Proximity from high data demand
Congestion (SAIDI at national level, 2019)
Loss of Load Expectation (2025)
Impact of additional 100MWh on peak demand (2018)
Share of RES in Energy Mix [2019]
Level of "greenness" of the carbon footprint [2019]
11
14
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1
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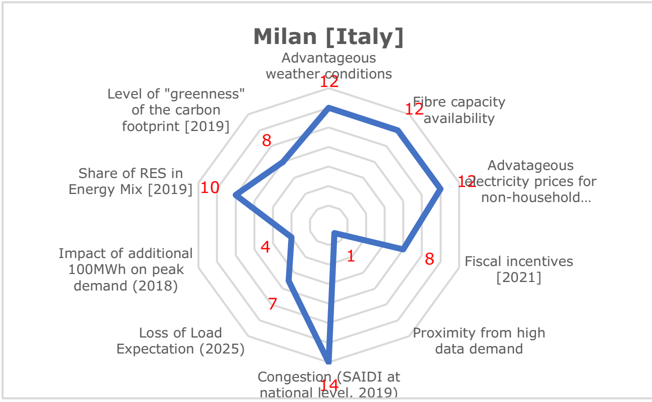
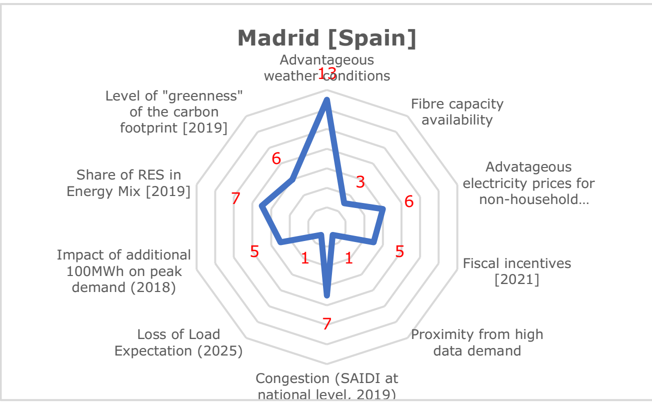
10
7


Milan [Italy]
Advantageous weather conditions
Fibre capacity availability
Advatageous electricity prices for non-household...
Fiscal incentives [2021]
Proximity from high data demand
Congestion (SAIDI at national level, 2019)
Loss of Load Expectation (2025)
Impact of additional 100MWh on peak demand (2018)
Share of RES in Energy Mix [2019]
Level of "greenness" of the carbon footprint [2019]
12
12
12
8
1
14
7
4
10
8


Madrid [Spain]
Advantageous weather conditions
Fibre capacity availability
Advatageous electricity prices for non-household...
Fiscal incentives [2021]
Proximity from high data demand
Congestion (SAIDI at national level, 2019)
Loss of Load Expectation (2025)
Impact of additional 100MWh on peak demand (2018)
Share of RES in Energy Mix [2019]
Level of "greenness" of the carbon footprint [2019]
13
3
6
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1
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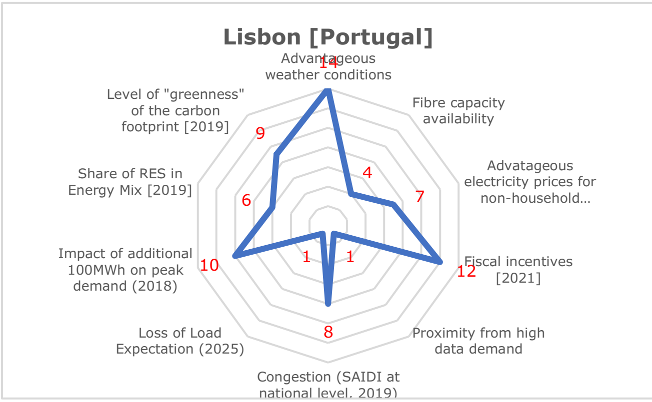
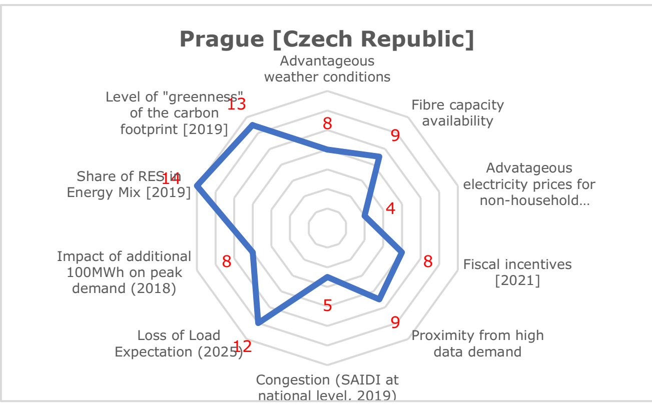
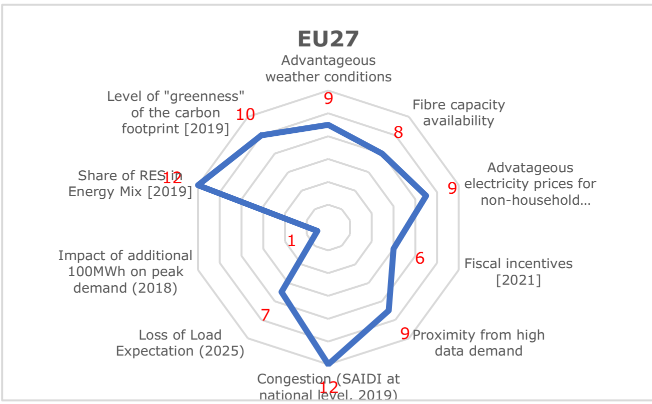
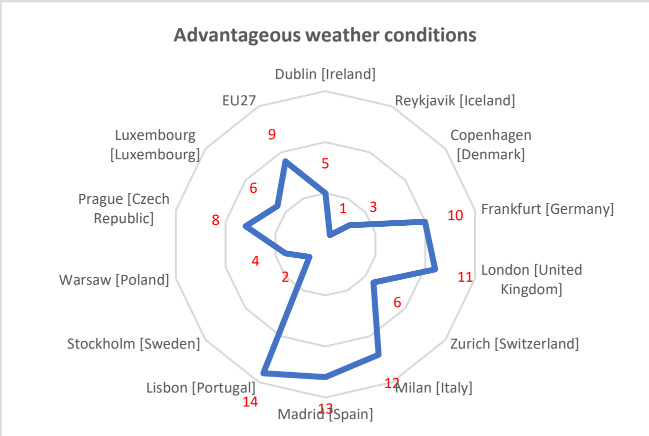
7
6

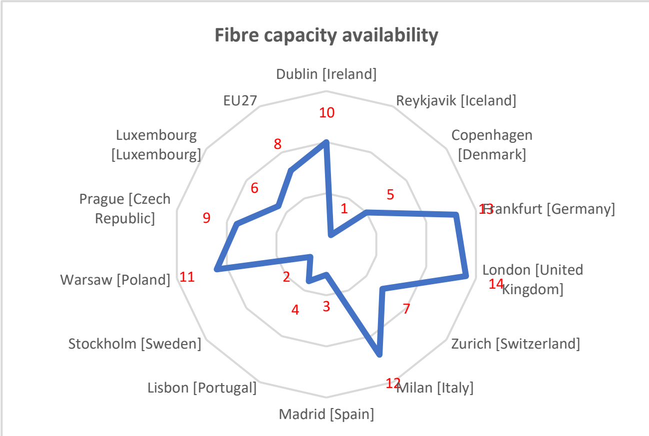

Lisbon [Portugal]
Advantageous weather conditions
Fibre capacity availability
Advatageous electricity prices for non-household...
Fiscal incentives [2021]
Proximity from high data demand
Congestion (SAIDI at national level, 2019)
Loss of Load Expectation (2025)
Impact of additional 100MWh on peak demand (2018)
Share of RES in Energy Mix [2019]
Level of "greenness" of the carbon footprint [2019]
14
4
7
12
1
8
1
10
6
9

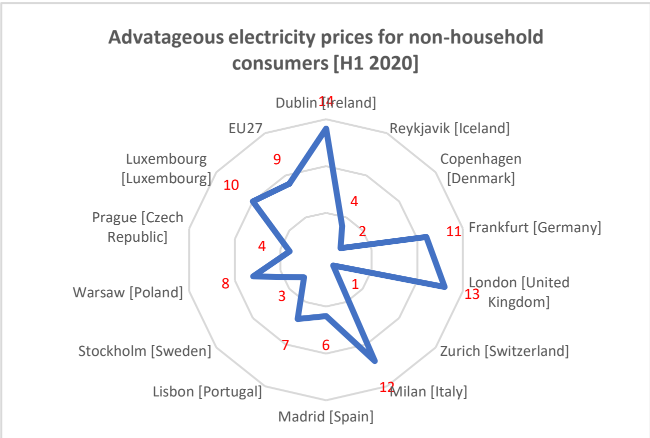

Prague [Czech Republic]
Advantageous weather conditions
Fibre capacity availability
Advatageous electricity prices for non-household...
Fiscal incentives [2021]
Proximity from high data demand
Congestion (SAIDI at national level, 2019)
Loss of Load Expectation (2025)
Impact of additional 100MWh on peak demand (2018)
Share of RES in Energy Mix [2019]
Level of "greenness" of the carbon footprint [2019]
8
9
4
8
9
5
12
8
14
13

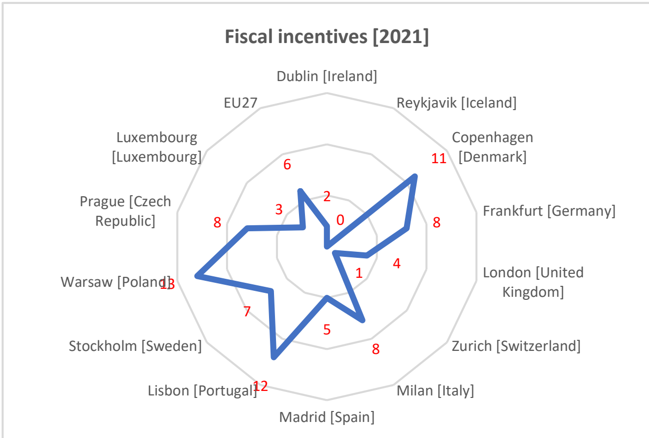

EU27
Advantageous weather conditions
Fibre capacity availability
Advatageous electricity prices for non-household...
Fiscal incentives [2021]
Proximity from high data demand
Congestion (SAIDI at national level, 2019)
Loss of Load Expectation (2025)
Impact of additional 100MWh on peak demand (2018)
Share of RES in Energy Mix [2019]
Level of "greenness" of the carbon footprint [2019]
9
8
9
6
9
12
7
1
12
10

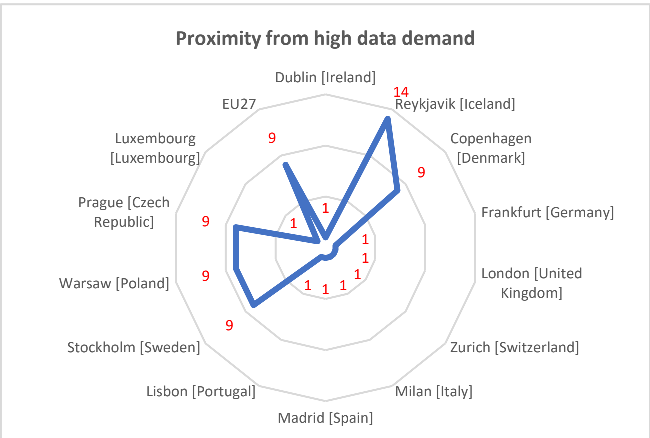
6.3 Annex 3 – Dimensions of attractiveness for different European cities (the higher the ranking, the closer to the graph's centre)

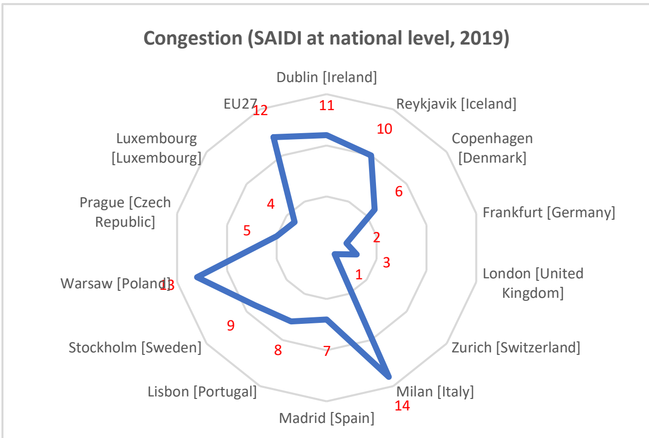


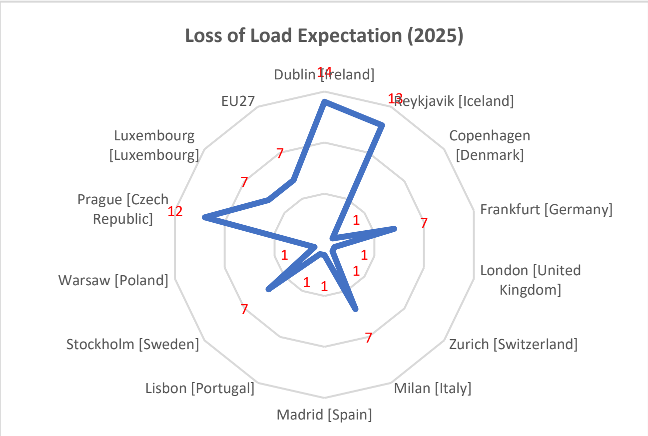


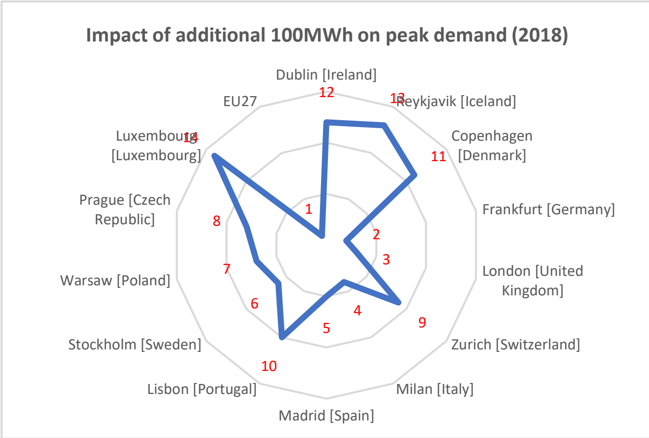









Loss of Load Expectation (2025)
Dublin [Ireland]
Reykjavik [Iceland]
Copenhagen [Denmark]
Frankfurt [Germany]
London [United Kingdom]
Zurich [Switzerland]
Milan [Italy]
Madrid [Spain]
Lisbon [Portugal]
Stockholm [Sweden]
Warsaw [Poland]
Prague [Czech Republic]
Luxembourg [Luxembourg]
EU27
14
13
1
7
1
1
7
1
1
1
7
12
7
7


Impact of additional 100MWh on peak demand (2018)
Dublin [Ireland]
Reykjavik [Iceland]
Copenhagen [Denmark]
Frankfurt [Germany]
London [United Kingdom]
Zurich [Switzerland]
Milan [Italy]
Madrid [Spain]
Lisbon [Portugal]
Stockholm [Sweden]
Warsaw [Poland]
Prague [Czech Republic]
Luxembourg [Luxembourg]
EU27
12
13
11
2
3
9
4
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7
8
14
1

6.4 Annex 4 - Origin and Corporate Reporting on Data Centre Energy Efficiency

Metrics	Proposed By	Discussed in	Utilisation level in Environmental/ Sustainability reports of the main players in the industry*:
PUE Power Usage Effectiveness	The **Green Grid (2007)**	**Yuventi** and **Mehdizadeh (2013)** **Brady** et al. (2013)	**90%**
DCiE Data Centre infrastructure Productivity	The **Green Grid (2007)**	**The inverse of PUE**	**0%**
CUE Carbon Usage Effectiveness	The **Green Grid (2010)**	**Alger (2013)**	**10%**
WUE Water Usage Effectiveness	The **Green Grid (2010)**	**Mytton (2021)**	**20%**
PPE Power to Performance Effectiveness	Gartner (2009)	**Capuccio (2009)**	**0%**
ERF Energy Reuse Factor	The **Green Grid (2010)**	**Wahlroos** et al. (2018) **Pärssinen** et al. (2018)	**0%**
EER Energy Efficiency Ratio	**Standard measure of heat pump efficiency**	**Ling** et al. **(2017)**	**0%**
COP Coefficient of Performance	**Standard measure of heat pump efficiency**	Wahlroos et al. (2017)	**0%**
DCeP Data Centre Energy Productivity	The **Green Grid (2009)**	**Daim** et al. (2009) **Sego** et al. (2012)	**0%**

* 10 Environmental/Sustainability Reports (2020) examined: Apple, Amazon, Microsoft, Google, Facebook, Equinix, Digitial Realty, Cyrus One, Global Switch**, Verizon
** Sustainability Report not available. The company's "Green Bond Framework" was considered.

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