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Energy Consumption in Data Centres and Broadband Communication Networks in the EU

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Abstract

Demand for digital services is rising rapidly, raising concerns about the energy use and environmental impacts of data centres and telecommunication networks. Despite the increasing public and policy interest in addressing these impacts, there is a lack of official statistics on the energy use of digital infrastructure. This study reviews and uses existing literature and public data sources to estimate the energy consumption of data centres and telecommunication networks in the European Union (EU-27) in 2022. Data centres in the EU used an estimated 45–65 TWh of electricity in 2022 (1.8–2.6% of total EU electricity use), while telecommunication networks used an estimated 25–30 TWh of electricity (1–1.2% of total EU electricity use). Network energy use as a share of national electricity use was both lower and more uniform than data centres. Policymakers and companies should work together to improve data collection, quality, and availability in order to better understand trends and make informed policy decisions to manage the energy and environmental impacts of digital infrastructure.

Executive Summary

Demand for digital services is rising rapidly, raising concerns about the energy use and environmental impacts of data centres and telecommunication networks. Despite the increasing public and policy interest in addressing these impacts, there is a lack of official statistics on the energy use of digital infrastructure. This study reviews and uses existing literature and public data sources to estimate the energy consumption of data centres and telecommunication networks in the European Union (EU-27) in 2022.

Data centres in the EU used an estimated 45–65 TWh of electricity in 2022, equivalent to 1.8–2.6% of total regional electricity consumption. The top four data centre markets – Germany, France, the Netherlands, and Ireland – accounted for nearly two-thirds of the region's data centre energy use, despite having less than 40% of the population. Data centres represent over 2% of national electricity use in Ireland (18%), the Netherlands (5.2%), Luxembourg (4.8%), Denmark (4.5%), and Germany (3%), Sweden (2.3%), and France (2.2%).

Telecommunication networks used an estimated 25–30 TWh of electricity, equivalent to 1–1.2% of total EU electricity use. The four largest Member States by population and GDP (Germany, France, Italy, and Spain) were also the four largest users of energy for telecommunication networks, accounting for 65% of the total. Network energy use as a share of national electricity use was both lower and more uniform compared with data centres, ranging from 0.5% to 1.5%. In contrast, data centres as a share of national electricity use range from as low as 0.4% in some countries to as high as 18% in Ireland.

The combined energy use of data centres and telecommunication networks in the EU was 70–95 TWh in 2022, equivalent to 2.8–3.8% of total regional electricity use. The four largest Member States – Germany, France, Italy, and Spain – accounted for about 60% of total digital infrastructure energy use in the region. Digital infrastructure accounts for more than 5% of national electricity use in four countries, each with major data centre markets: Ireland (19%), the Netherlands (6%), Luxembourg (5.5%), and Denmark (5%).

Policymakers and companies must work together to improve data collection, quality and availability. While the estimates of this study represent a likely range of figures, it is critical to develop more robust estimates to better understand trends and make informed policy decisions to manage the energy and environmental impacts of digital infrastructure. Governments and statistical agencies should develop standardised definitions and classifications for data centres and networks, such as providing criteria and guidance on classifying different data centre types. Governments and companies should work together to improve data quality and availability regarding data centre energy consumption (by size and type), telecommunication network energy use (by type), as well as relevant activity indicators (e.g. connections, data traffic, data centre workloads). Data collection efforts should also seek to better understand energy use characteristics and implications of specific services and tasks such as artificial intelligence.

1. Introduction

1.1 Background

Digital infrastructure – data centres and telecommunication networks – are at the heart of the digital transformation, underpinning all aspects of our increasingly digitalised and connected societies.

Demand for their services is rising rapidly, raising concerns about their energy use and environmental impacts. Between 2015 and 2022, the number of internet users globally increased by 80%, internet traffic increased five-fold, while data centre workloads more than quadrupled (IEA, 2023a; ITU, 2023; Cisco, 2019; TeleGeography, 2022, 2023; Cisco, 2018; Masanet et al., 2020).

However, energy efficiency improvements in computation, data storage, and data transmission have helped to limit energy demand growth globally. Between 2015 and 2022, data centre and network energy demand grew at a much slower pace (+2–8% CAGR) than data traffic (+24% CAGR) or data centre workloads (+33% CAGR) (Table 1). Data centres and data transmission networks each accounted for 1–1.5% of global electricity use globally in 2022 (IEA, 2023a).

Table 1. Global trends in digital and energy indicators, 2015–2022

	2015	2022	Change
Internet users	3 billion	5.3 billion	+78%
Internet traffic	0.6 ZB	4.4 ZB	+600%
Data centre workloads	180 million	800 million	+340%
Data centre energy use (excluding crypto)	200 TWh	240–340 TWh	+20–70%
Crypto mining energy use	4 TWh	100–150 TWh	+2300–3500%
Mobile subscriptions	7.1 billion	8.3 billion	+17%
Fixed broadband subscriptions	790 million	1.2 billion	+51%
Data transmission network energy use	220 TWh	260–360 TWh	+18–64%

Sources: IEA (2023a); Malmodin et al. (2023)

In contrast to modest growth at the global level, there has been significant growth in some countries, especially for data centre energy use. In Ireland, for example, data centre energy use more than tripled between 2015 and 2022, growing to 18% of national electricity use in 2022 (Central Statistics Office, Ireland, 2022).

In the European Union (EU), there is a lack of recent and comprehensive estimates of the energy consumption of data centres and telecommunication networks. In order to formulate effective policies to manage the energy use of digital infrastructure, policymakers require better understanding of data centre and network energy consumption.

1.2 Objectives and approach

The objective of this study is to estimate the energy consumption of data centres and telecommunication networks in the European Union (EU-27). In order to develop these estimates, a comprehensive literature assessment was conducted to compile available data to inform the development of a simplified model to estimate data centre and network energy use at the national and EU-27 levels.

Section 2 summarises the literature review of ICT energy estimates from a range of available sources, including government data and reports, peer-reviewed journal articles, industry data and reports, and other grey literature. The section also reviews literature estimating the energy use of emerging digital technologies and services such as AI, blockchain and cryptocurrencies, streaming and gaming.

Section 3 summarises the modelling methodology used to estimate EU-27 energy consumption of data centres and networks in 2022, including key data sources and assumptions.

Section 4 summarises the results and discusses key strengths and limitations of the analysis.

Section 5 concludes the reports with key recommendations for future data collection efforts.

2. Literature review

2.1 Introduction

National statistical agencies and regional and intergovernmental organisations such as the European Commission (Eurostat, 2023) and the International Energy Agency (IEA, 2023b) collect and publish official statistics on the energy use of many energy end-use sectors and services (e.g. steel, road transport, lighting). However, to date, there is a lack of official statistics on the energy use of the information and communications technology (ICT) sector[1] at the national, regional, and global levels.

Since 2018, only a few studies have comprehensively estimated the energy consumption of the entire ICT sector (4E EDNA, 2019, 2021; Andrae, 2019, 2020; ITU, 2020; Malmodin et al., 2023; Malmodin & Lundén, 2018; The Shift Project, 2019b, 2020a, 2021). However, as these studies do not include any regional disaggregation in their published materials, estimates for Europe or individual European countries are not available.

The literature review (Task 1) identified and summarised the studies and estimates published since 2018, focusing on data centres and Europe. This section summarises the key findings from the literature review.

2.2 Modelling approaches

Studies that have estimated the energy use of data centres and telecommunication networks at the global, regional, and national levels have employed a variety of modelling approaches. These methodologies can be broadly categorised into one of three types (or a combination) – bottom-up, top-down, and extrapolation – each with their own advantages and disadvantages (Mytton & Ashtine, 2022).

Bottom-up studies use detailed data on technology such as equipment specifications (e.g. server power draw), data centre infrastructure characteristics (e.g. power usage effectiveness [PUE]) and installed base and equipment shipment values. The main advantage of these studies is that they have substantial explanatory power and they can be useful for exploring the potential effects of policies, technologies, and other trends. However, their substantial data requirements make these studies very resource- and time-intensive to produce. Some data inputs such as proprietary market data can be very expensive and cannot be shared, limiting transparency.

Some bottom-up studies have used high-level parameters such as data centre floor space or the number of data centres to estimate data centre energy use. Given the uncertain (and relatively weak) relationship between these parameters and energy use, studies using these methods are less certain and credible compared with those that use technology-level data such as the number of installed servers and their energy use characteristics.

Top-down estimates compile measured or estimated energy consumption data from governments and companies. Their main advantage is that they are accurate, being based on reliable data, and easy to generate and update. But the limited availability of data from governments and companies currently means that only a portion of the overall scope can be reliably estimated, requiring other complementary approaches to ensure comprehensive coverage.

Extrapolation approaches combine high-level activity indicators such internet protocol (IP) traffic with energy intensity assumptions to project total energy use under different activity and efficiency improvement scenarios. They require a baseline energy consumption estimate from a bottom-up or top-down model, and decisions around assumed growth rates (e.g. energy efficiency improvement, data volume growth). These studies are typically more transparent and relatively easy to generate and update. Their main disadvantages are their low explanatory power and a higher risk of mis-use (e.g. developing exaggerated estimates from long-term projections).

[1] According to the ITU-T L.1450 Recommendation, for the purposes of assessing the environmental impact of the ICT sector, the sector boundary includes: i) ICT end-user goods (e.g. computers and computer peripherals, consumer electronics for communications purposes such as mobile phones, tablets, laptop PCs and home network goods, and IoT devices); ii) ICT network goods (e.g. telecommunication core networks and access networks); iii) data centres; and iv) ICT services (e.g. software development) (ITU, 2018)

Hybrid estimates combine a combination of approaches, typically combining available top-down data from governments and companies with bottom-up data or extrapolation approaches using available data.

2.3 Data centres

Global estimates

Since 2018, several institutions and researchers have estimated the global energy use of data centres[2], employing a range of scopes, methodologies, assumptions, and data sources (Annex, Table A.1).

There is a significant range in the estimates, ranging from around 200 TWh to nearly 1,000 TWh for the year 2020. If outlier figures from studies that extrapolate outdated assumptions or analyses are excluded (Belkhir & Elmeligi, 2018; The Shift Project, 2019b, 2021), this range narrows significantly to 200–380 TWh in 2020 (excluding cryptocurrencies), equivalent to 0.8–1.6% of global electricity consumption. Cryptocurrencies accounted for an additional 80–100 TWh in 2020, or around 0.4% of global electricity use (IEA, 2021).

European estimates

Several studies have estimated data centre energy consumption for Europe or the European Union over the past few years, primarily funded or co-authored by the European Commission and European Union.

The three most recent reports were published in 2020, prepared for different departments of the European Commission:

- A report co-authored by the Joint Research Centre Product Bureau and consultants (Viegand Maagøe, Operational Intelligence, Hansheng, Ballarat Consulting) estimated that data centres in the EU consumed 104 TWh in 2020 (Dodd et al., 2020). Enterprise data centres accounted for 44% of the total, while colocation and managed service providers (e.g. cloud) accounted for 56%. They also projected energy consumption would grow to 134 TWh in 2025 and 160 TWh in 2030.
- A report prepared for DG ENER by consultants VHK and Viegand Maagøe estimated that data centres in the EU27 consumed 39.5 TWh in 2020 (VHK & Viegand Maagøe, 2020). This estimate was based on the disaggregated estimate for Western Europe in Masanet et al. (2020).
- A report prepared for DG CONNECT by the Environment Agency Austria and the Borderstep Institute found that data centre energy consumption in the EU28 increased from 53.9 TWh in 2010 to 76.8 TWh in 2018 (Montevecchi et al., 2020). Based on current trends, they projected energy use would grow to 92.6 TWh in 2025 and 98.5 TWh in 2030.

Table 2. Overview studies estimating the energy use of data centres in Europe since 2018

Publication	Approach	Estimate	Quality assessment
Bashroush (2018)	Methodology not disclosed.	130 TWh in 2017	Low – no details available to assess
BloombergNEF et al. (2021)	Bottom-up estimate of colocation and hyperscale data centres based on data from Eaton on installed data centre capacity in each country, public announcements, assumed rack capacities, and lease rates.	26 TWh in 2021 for Germany, Ireland, Netherlands, Norway, and the United Kingdom	Medium-high – high quality analysis but limited geographic scope and excludes small data centres
Dodd et al. (2020)	Estimate based on data from 2013 data from DCD supplemented by surveys on data centre area, installed capacities, and other studies from the US and Europe including the Code of Conduct.	74 TWh in 2015 104 TWh in 2020 for EU27 Projections: 134 TWh in 2025 and 160 TWh in	Low-medium

[2] See Mytton & Ashtine (2022) for a comprehensive and critical review of 258 data centre energy estimates published between 2007 and 2021.

Publication	Approach	Estimate	Quality assessment
		2030	
Masanet et al. (2020)	Bottom-up estimate based on stock and shipment data for servers, drives, networking, their energy use characteristics and lifespans, combined with assumptions for each type of data centre class and region-specific PUE.	39.4 TWh in 2018 for Western Europe	Medium-high
Montevecchi et al. (2020)	Bottom-up estimate based on data centre market developments, technical characteristics of servers, storage, and networking (energy use, age) and data centre infrastructure (air conditioning, power supply, UPS).	76.8 TWh in 2018 for EU28 (2.7% of EU28) Projections: 92.6 TWh in 2025 and 98.5 TWh in 2030	Medium
VHK & Viegand Maagøe (2020)	Based on Masanet et al. (2020).	39.5 TWh in 2020 for EU27	Same as Masanet et al. (2020)

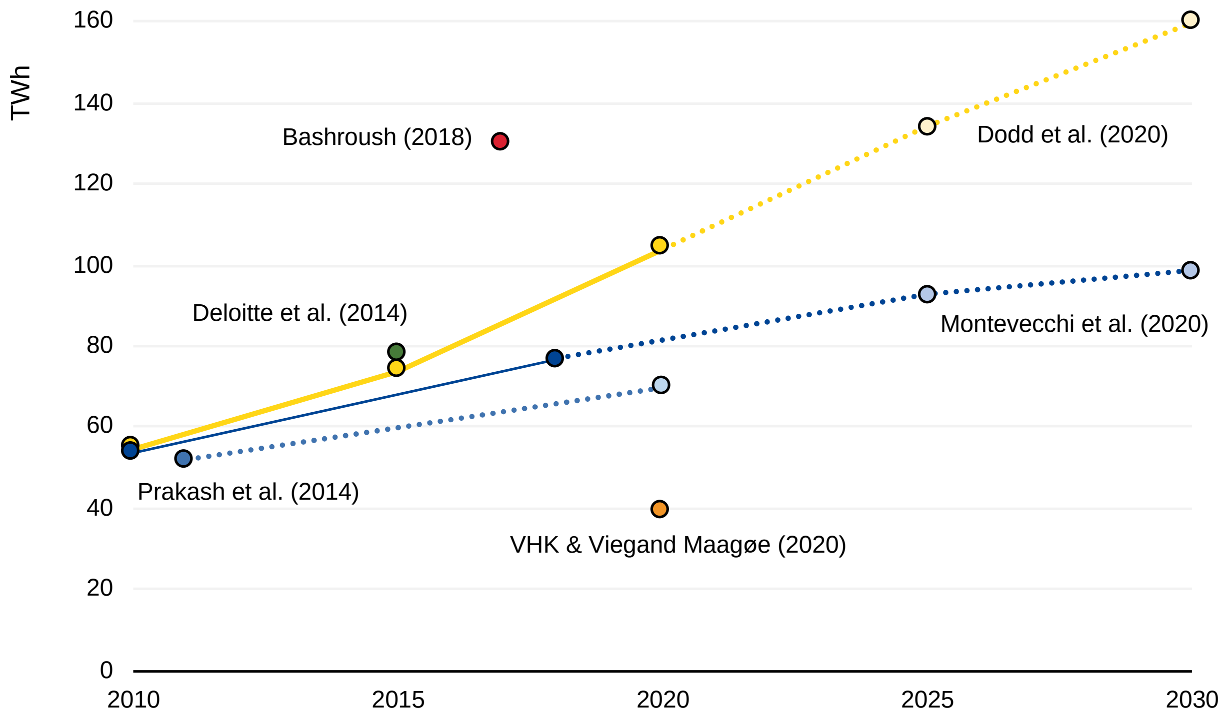
Source: JRC

There is a large range in the results; for example, estimates for 2020 range from 39.5 TWh to 104 TWh, and projections for 2030 range from 98.5 TWh to 160 TWh. The large range stems from substantial differences in data sources, assumptions, and methodologies, which are summarised in Table 2. However, the lack of details and documentation regarding assumptions and methodology makes it difficult to compare underlying differences, and how they contribute to diverging estimates.

Older reports on the topic include 2014 reports prepared for DG CONNECT (Prakash et al., 2014) and DG GROW (Deloitte et al., 2014), as well as a 2017 report funded under the EU Horizon 2020 programme (Bashroush, 2018). Prakash et al. (2014) estimated that data centre energy use in the EU27 would increase from 52 TWh in 2011 to 70 TWh in 2020. Deloitte et al. (2014) estimated that data centres consumed 78 TWh in the EU28 in 2015. Bashroush (2018) estimated 130 TWh in 2017. The results of the studies published since 2014 are summarised in Figure 1.

Two other studies have estimated the energy consumption of data centres in Europe. The global study by Masanet et al. (2020) includes disaggregated estimates for “Western Europe”, with an estimate of 39.4 TWh in 2018. BloombergNEF, Statkraft, and Eaton published a joint study in 2021 focusing on colocation and hyperscale data centres in Germany, Ireland, Netherlands, Norway and the United Kingdom (BloombergNEF et al., 2021).

Figure 1. Summary of European data centre energy estimates



Note: Darker circles indicate estimates; lighter circles and dotted lines indicate projections.

Source: JRC

Country-level estimates

There are country-level estimates of many of the largest data centre markets in Europe. The most credible estimates are based on reported electricity consumption and metering data (Ireland, the Netherlands, Finland) as well as bottom-up estimates using robust models developed over many years (Germany). Most estimates focus on colocation and hyperscale data centres.

Country-level estimates from within the EU-27 are summarised in Table 3, and include the following:

- **Belgium:** The Belgian Digital Infrastructure Association, based on research by consultants Pb7, estimated that colocation and hyperscale data centres used 380 GWh in 2021 (Belgian Digital Infrastructure Association, 2022).
- **Denmark:** The Danish Energy Agency commissioned a study in 2021 which estimated that data centres consumed 0.88 TWh in 2020 (COWI, 2021), and have since published data centre energy consumption estimates in their annual Energy and Climate Outlook, with an estimate of 1.1 TWh in 2021 (Danish Energy Agency, 2023a).
- **Finland:** The Research Institute of the Finnish Economy (ETLA) estimated that data centres consumed around 250 GWh in 2018 based on reported electricity consumption of the two-digit level industrial classification covering data centres (Hiekkanen et al., 2021).
- **France:** The French environment agency (Ademe) and telecommunications regulator (Arcep) jointly published a study in 2022 estimating the total energy consumption of data centres in France at 11.6 TWh in 2020 (Ademe & Arcep, 2022). They found that colocation (49%) and enterprise data centres (36%) account for the vast majority of total data centre energy use. GreenIT.fr estimated that data

centres in France consumed 5.2 TWh[3] in 2020 (Bordage et al., 2021). A report commissioned by the French Senate estimated that data centres in France consumed around 9 TWh in 2019 (CITIZING, 2020).

- **Germany:** The Borderstep Institute estimated that data centres in Germany consumed 14 TWh in 2018, 16.3 TWh in 2020, 17 TWh in 2021, and 17.9 TWh in 2022 (Hintemann et al., 2023; Hintemann & Hinterholzer, 2020, 2022). Based on current trends, they project data centre energy consumption could reach 27 TWh in 2030 (Hintemann et al., 2023). BloombergNEF estimates that colocation and hyperscale data centres in Germany used 7.2 TWh in 2021 (BloombergNEF et al., 2021).

- **Ireland:** The Central Statistics Office (CSO) analysed meter data from the Irish electricity utility ESB to estimate the combined electricity consumption of all meters that were primarily being used for data centre activities. The CSO estimate that data centres used 2.5 TWh in 2019 (9% of national electricity consumption), 3 TWh in 2020 (11%), 4 TWh in 2021 (14%), and 5.25 TWh in 2022 (18%) (Central Statistics Office, Ireland, 2021, 2022, 2023). The study found that a small number of large data centres accounted for most of the metered electricity consumption. BloombergNEF estimated that hyperscale and colocation data centres in Ireland consumed 4.7 TWh in 2021 (BloombergNEF et al., 2021).

- **Netherlands:** Based on business registration data and electricity consumption data from the regional grid operator TenneT, Statistics Netherlands estimated that data centres consumed 1.6 TWh in 2017, 2.4 TWh in 2018, and 2.7 TWh in 2019 (Statistics Netherlands, 2021a). Larger data centres (consuming more than 7.5 GWh) accounted for 90% of the 2019 total. BloombergNEF estimated that colocation and hyperscale data centres in the Netherlands used 6.3 TWh in 2021 (BloombergNEF et al., 2021).

- **Sweden:** The Swedish Energy Agency and the Research Institutes of Sweden (RISE) estimate that data centres in the country used 2.8–3.2 TWh in 2022. Radar, an IT consulting firm, estimated that Swedish data centres used 2.4 TWh of electricity in 2020. They estimate floor space of 20 hectares, total capacity of 640 MW, and 43% power utilisation.

Table 3. Overview studies estimating the energy use of data centres in Europe since 2018

Country	Publication	Approach	Estimate	Quality assessment
Belgium	Belgian Digital Infrastructure Association (2022)	Based on research conducted by Pb7 (consultants); details of methodology not provided.	0.38 TWh in 2021	Low-medium
Denmark	COWI (2021)	Historical estimates based on data centre characteristics, data traffic, and other national and international studies.	0.88 TWh in 2020	Medium
	Danish Energy Agency (2021; 2022a; 2022b; 2023a)	Based (COWI, 2021) and expected power utilisation data from the transmission system operator, Energinet.	1.1 TWh in 2021	Medium
Finland	Hiekkanen et al. (2021)	Based on the reported electricity consumption of the two-digit level industrial classification covering data centres (Computer and information service activities, TOL 62–63).	0.25 TWh in 2018	High
France	Ademe & Arcep (2022)	Based on publicly available data on colocation data centres and assumptions for data centre area (by type) and energy	11.6 TWh in 2020	Medium

[3] The report estimates total electricity consumption for digital technologies in 2020 of 40 TWh, of which 13% was consumed in the use phase by data centres.

Country	Publication	Approach	Estimate	Quality assessment
		characteristics from previous studies.		
	Bordage et al. (2021)	Based on the number of servers in operation from University of Sherbrooke and some assumed energy “impact factor” and average PUE of 1.7.	5.2 TWh in 2020	Low
	CITIZING (2020)	Extrapolation approach based on data traffic to and from data centres and assumed energy intensity.	9 TWh in 2019	Low
Germany	Hintemann et al. (2023); Hintemann & Hinterholzer (2020; 2022)	Bottom-up estimate based on data centre market developments, technical characteristics of servers, storage, and networking (energy use, age) and data centre infrastructure (air conditioning, power supply, UPS).	14 TWh in 2018 16.3 TWh in 2020 17 TWh in 2021 17.9 TWh in 2022	High
	BloombergNEF et al. (2021)	Bottom-up estimate of colocation and hyperscale data centres (details in Table 2).	7.2 TWh in 2021	Medium-high
Ireland	Central Statistics Office, Ireland (2021; 2022; 2023)	Based on meter data from electricity utility to estimate the combined electricity consumption of all meters that were primarily being used for data centre activities.	2.5 TWh in 2019 3 TWh in 2020 4 TWh in 2021 5.3 TWh in 2022	High
	BloombergNEF et al. (2021)	Bottom-up estimate of colocation and hyperscale data centres (details in Table 2).	4.7 TWh in 2021	Medium-high
Netherlands	Statistics Netherlands (2021a)	Based on business registration data and electricity consumption data from the regional grid operator TenneT.	1.6 TWh in 2017 2.4 TWh in 2018 2.7 TWh in 2019	High
	BloombergNEF et al. (2021)	Bottom-up estimate of colocation and hyperscale data centres (details in Table 2).	6.3 TWh in 2021	Medium-high
Sweden	Swedish Energy Agency (2023)	Based on available reports, interviews, and statistical data.	2.8–3.2 TWh in 2022	Medium-high
	Radar (2020)	Analysis of quantitative data and previous reports complemented by qualitative information from interviews.	2.4 TWh in 2020	Medium-high

Source: JRC

There are several published country-level estimates for important European data centre markets outside the EU-27, notably Norway and the United Kingdom:

- **Norway:** The Norwegian Water Resources and Energy Directorate (NVE) estimate that data centres in Norway consumed 0.8 TWh in 2019 (NVE, 2020). The report also projects data centres to consume 4–9 TWh in 2040. BloombergNEF estimates that colocation and hyperscale data centres in Norway used 0.7 TWh in 2021 (BloombergNEF et al., 2021).
- **United Kingdom:** National Grid ESO, the national the UK’s national electricity system operator, estimates that data centres used 4–7 TWh of electricity in 2020, equivalent to 1.3–2.5% of national electricity use (National Grid ESO, 2022). BloombergNEF estimates that colocation and hyperscale data centres in the United Kingdom used 7.2 TWh in 2021 (BloombergNEF et al., 2021).

Outside of Europe, there are national level estimates on data centre energy use covering the largest data centre markets in the world. In the **United States**, data centres consumed 70 TWh in 2014 (1.8% of national electricity use) and projected to rise to 73 TWh in 2020 based on current trends (Shehabi et al., 2016, 2018). In **China**, some studies have estimated that data centres[4] consumed 150–200 TWh in 2020, or around 2% of national electricity use (Fan, 2021; Greenpeace East Asia, 2021; Greenpeace East Asia & North China Electric Power University, 2019). In **Japan**, data centres used around 20 TWh in 2021, or 2% of national electricity consumption (Deloitte Tohmatsu MIC Research Institute, 2022; Nikkei, 2022). In **Singapore**, data centres accounted for around 7% of national electricity consumption in 2020 (Singapore Ministry of Communications and Information, 2021).

2.4 Telecommunication networks

There are only a few estimates on the global estimates for telecommunication network energy use. Malmodin et al. (2023) estimate that networks consumed 244 TWh in 2020, or around 1% of global electricity use. Coroamă (2021) reviewed bottom-up and top-down studies to estimate that networks consumed 340 TWh in 2020 (1.4% of global electricity). The GSMA estimated that telecommunication network operators used 293 TWh of electricity in 2021[5] (GSMA, 2022).

The energy use of European network operators was estimated by Lundén et al., (2022) based on publicly reported data on energy use of operators covering 36% of European subscriptions. They estimated that European network operators in used 38 TWh in 2018 (EU28) and 29 TWh in 2020 (EU27), equivalent to around 1.2% of total regional electricity use.

Several national regulatory agencies in Europe have compiled and published estimated energy consumption of telecommunication networks in their countries (BEREC, 2023):

- **Belgium:** The three major telecom operators consumed an estimated 624 GWh of electricity in 2021, of which 481 GWh was consumed in networks (0.7% of national electricity use) (BIPT, 2022). Mobile networks accounted for 60% of total network energy use[6].
- **Finland:** Communications networks consumed an estimated 650 GWh in 2021 (0.75% of national electricity use) (Traficom, 2022). Mobile networks accounted for 58% of total network energy use (Traficom, 2023).
- **France:** Data networks consumed 3.9 TWh of electricity in 2021, equivalent to 0.8% of national electricity use (Arcep, 2022, 2023a, 2023b). Mobile networks accounted for nearly 60% of the total. Total network energy use was up 3% from 2020 levels. Data network energy use has increased 25% since 2017, representing a compound annual growth rate of 6%.

2.5 Digital technologies and services

Emerging technologies such as artificial intelligence (AI), blockchain, and 5G are poised to boost demand for digital infrastructure. These technologies and trends could have different implications for energy use in data centres, networks, and devices, with some technologies such as AI and blockchain primarily impacting data centres while 5G and IoT likely to affect networks and devices.

Artificial intelligence

Artificial intelligence (AI) is likely to have significant implications for data centre energy use in upcoming years. Early studies on the energy and carbon footprint of AI and machine learning (ML) focused on the energy and carbon emissions associated with *training* large language models (Lacoste et al., 2019; Luccioni et

[4] Some references to these reports note that the energy totals include 5G energy consumption. The exact scope and methods cannot be verified as the original report could not be located.

[5] This estimate includes all uses of electricity by network operators, including networks, data centres, offices, and stores. Based on available company-level data regarding electricity use between these end uses, it is likely that networks typically accounted for 70–90% of the total for most operators, with the exception of those with substantial data centre businesses.

[6] This figure is based on data from Orange and Telenet, which together account for 43% of energy use by network operators, as disaggregated data for the largest operator (Proximus) was not available.

al., 2020; Schwartz et al., 2019; Strubell et al., 2019). But training a single ML model represents only a small fraction of the overall energy use of AI.

Recent data from Meta (Wu et al., 2022) and Google (Patterson et al., 2022) indicate that the training phase only accounts for around 20–40% of overall ML-related energy use, with 60–70% for inference (application/use and up to 10% for model development (experimentation). A Danish researcher estimated that ChatGPT used around 4 GWh in January 2023 (Ludvigsen, 2023a, 2023b), about three times more electricity than was used to train GPT-3 (Patterson et al., 2022), the model that provides the basis for ChatGPT.

Only a fraction of total ICT energy use is attributable to AI and ML, but its exact share is not known due to challenges in boundary definition and a lack of data and established methodology (Kaack et al., 2022). Based on estimates of global ICT energy use (IEA, 2023a; Malmodin et al., 2023) and shares of data centre workloads and data centre IP traffic attributed to AI (Cisco, 2018; Compton, 2018), Kaack et al. (2022) estimated that AI likely accounted for less than 0.2% of global electricity use in 2021 (50 TWh). Other researchers have estimated future potential AI energy consumption based on energy use characteristics and projected shipments of servers (Vries, 2023).

Google estimated that ML accounted for 10–15% of their total energy use in recent years (i.e. 2–3 TWh in 2021), but noted that it is growing at a similar rate as overall company-wide energy use – around 20–30% per year (Google, 2022; Patterson et al., 2022). Computing demand for ML training and inference at Meta have increased by more than 100% per year in recent years, while overall data centre energy consumption grew about 40% per year (Meta, 2022; Naumov et al., 2020; Park et al., 2018).

The combination of the rapid growth in the size of the largest models (OpenAI, 2018) and ML compute demand (Wu et al., 2022) are likely to outpace strong energy efficiency improvements resulting in a net growth in total AI-related energy use in the coming years. Although AI itself can help reduce energy use in data centres (DeepMind, 2016; Luo et al., 2022), the rapid and mainstream adoption of AI chatbots like OpenAI's ChatGPT and Google Bard are likely to accelerate energy demand growth for AI.

Blockchain and cryptocurrencies

Blockchain and other distributed ledger technologies are major energy users. Bitcoin – the most prominent example of proof-of-work blockchain and most valuable cryptocurrency by market capitalisation – consumed around 95 TWh in 2022, equivalent to 0.4% of global electricity use (Cambridge Centre for Alternative Finance, 2023). While this was similar to its electricity use in 2021, it is 17-times higher than its energy use in 2016.

Ethereum, second behind Bitcoin in terms of market capitalisation and energy use, consumed around 18 TWh over the first three quarters of 2022 (McDonald, 2022). In September 2022, Ethereum transitioned from a proof-of-work consensus mechanism to proof-of-stake, which slashed energy use by more than 99.95% (CCRI, 2022; ethereum.org, 2023).

Gallersdörfer et al. (2020) estimated that Bitcoin and Ethereum accounted for 80% of all crypto-related energy use in 2020. The same authors estimated that cryptocurrencies as a whole consumed around 150 TWh in 2022 (CCRI, 2023).

Streaming media and cloud gaming

The delivery of streaming videos, music, and gaming from a content provider to the viewer is associated with energy consumption across the ICT system, including in data centres, telecommunication networks, customer premises equipment (e.g. routers), and end user devices.

The energy and carbon footprint of streaming video has attracted significant attention from researchers, companies, and the media over the past few years. Much of this attention can be traced back to media headlines from 2019 quoting the Shift Project claiming that half an hour of streaming emitted as much CO_2 as driving four miles (6,100 Watt-hours (Wh) per viewing hour) (AFP, 2019; Sparks, 2019; The Shift Project, 2019a), which was later revised downwards by 88% after correcting a unit conversion error (The Shift Project, 2020b). Marks et al. (2020) estimated that streaming 35 hours of HD video consumes 382 kWh (11,000 Wh per hour), but have since revised their estimate downwards by over 90% to 780–980 Wh (Makonin et al., 2022). These studies overestimate energy use – particularly by networks – by using outdated energy intensity values (kWh/GB) and assuming that energy use is proportional to data traffic (i.e. doubling bitrate doubles energy use).

These figures are substantially higher than more recent estimates published by the IEA (80–180 Wh per hour) and the Carbon Trust (220 Wh) (Kamiya, 2020b, 2020a; The Carbon Trust, 2021). A July 2023 study published by the European Commission estimated that a typical hour of streaming in Europe uses 50 Wh (EC DG Energy et al., 2023). Outdated energy intensity assumption and the use of faulty methodologies have resulted in some studies significantly overestimating the energy and carbon footprint of streaming video, particularly from data transmission (Moulierac et al., 2023). Based on typical viewership patterns today, the vast majority of total end-to-end energy use (i.e. from the data centre to the viewing devices) is consumed by end user devices and home networking equipment (The Carbon Trust, 2021).

Online gaming typically consumes more energy than streaming video, both from higher data intensity and from using more energy intensive devices. Aslan (2020) compared the carbon intensity of different gaming methods, and found that downloading was the least carbon intensive (47g CO_2e per hour), followed by disc (55g) and cloud (149g). Mills et al. (2019) also found that cloud gaming is up 30-300% more energy intensive than local gaming, consuming 100–1000 kWh annually per user (Cardoso, 2020). They also estimate that gaming could consume 34 TWh in 2016 in the United States.

5G and the Internet of Things

Mobile data traffic is projected to continue growing quickly, more than tripling between 2023 and 2028 (Ericsson, 2022). 5G's share of global mobile data traffic is projected to rise to 70% by 2028, up from 27% in 2023, driven by early adopters of 5G, including the United States, China, the Republic of Korea and European countries.

5G networks are expected to be more energy efficient than 4G networks per unit of traffic and benefit from improved sleep modes (Johnson, 2018; Orange, 2022; STL Partners, 2019). But higher traffic volumes and a higher number of base stations are likely to increase overall energy and emissions, as indicated by studies from developed countries like France, Switzerland and the United Kingdom (Bieser et al., 2020; Haut Conseil pour le Climat, 2020; Williams et al., 2022).

IoT adoption is expected to grow rapidly over the next five years, reaching 35 billion connections by 2028 (Ericsson, 2022). The low latency and high data throughput of 5G is also expected to accelerate cellular IoT adoption, which could double to 5.5 billion connections. IoT devices are generally expected to be energy efficient, but the sheer growth in the number of IoT devices could have important implications for standby energy use and embodied energy and material in IoT devices.

3. Data collection and modelling

3.1 Introduction

A mixed-method approach was used to develop a simplified spreadsheet model to estimate country-level energy use. The model uses country-level data centre and network energy use estimates where available. For countries without country-level data, estimates are derived using a variety of relevant indicators.

This section summarises the development of the simplified model (Task 2), including data sources, assumptions, and methodologies.

3.2 Data centres

Data collection

Data centre energy use estimates were collected from government reports, data, and other reputable sources (see 2.3 Data centres). Other relevant bottom-up data on data centres (e.g. IT capacity, data centre floorspace, PUE) were collected from a range of reputable sources, including governments, national data centre industry associations, and data centre market research companies. These additional data sources are summarised in Table 4.

Other relevant country-level indicators were collected from Eurostat and the ITU, including population, GDP, national electricity use, industrial electricity prices, household internet access, mobile internet access rates, and mobile broadband subscription.

Modelling approach

Depending on the available data for a given country, different modelling approaches were used:

- If country-level data centre energy use estimates were available from a reputable source using credible methods, this was used as the primary basis for developing country-level estimates. In some cases where coverage was incomplete, for example, where the estimate only covers colocation and hyperscale data centres, this was supplemented with assumptions from other bottom-up studies. Eight countries were estimated using this approach (Belgium, Denmark, Finland, France, Germany, Ireland, Netherlands, and Sweden), collectively covering nearly 80% of EU-27 data centre capacity, 62% of GDP, 55% of electricity use, and 46% of population.

- If energy use estimates were not available, a modelled estimate was derived using data on installed IT capacity or data centre IT floorspace, combined with appropriate assumptions on utilisation rates, PUE, and power density from other credible studies. Five countries were estimated using this approach (Austria, Italy, Luxembourg, Poland, and Spain) covering for around 18% of EU-27 data centre capacity, nearly 30% of GDP and electricity use, and one-third of population.

- For countries without any available IT-related data, relevant economic, energy, and digital indicators were used to derive a first-order estimate. For example, assuming a given share of national service sector electricity use for data centres based on other countries with similar economic and digital indicators.

In some cases, the available energy use estimates or IT capacity data did not cover all sizes and types of data centres, for example, including only colocation data centres. In these cases, estimates on energy use of other data centre types were derived by adapting assumptions from bottom-up studies (e.g. Ademe & Arcep, 2022; Hintemann et al., 2023; Hintemann & Hinterholzer, 2022; Montevecchi et al., 2020). If 2022 data were not available, historical average growth rates (where available and appropriate) were applied.

Given the uncertainties in chosen assumptions, central estimates were complemented with optimistic and pessimistic assumptions to develop a range of estimates for each country.

Table 4. Data sources and modelling approaches taken for data centres

Country	Available data and sources	Approach taken	Assessment quality
Austria	Total IT capacity (Mordor Intelligence, 2023); colocation IT capacity (Baxtel, 2023).14/02/2024 15:13:00	Estimated based on IT capacity estimates (Baxtel, 2023a; Mordor Intelligence, 2023) and assumptions from other studies and countries (Ademe & Arcep, 2022; Hintemann et al., 2023).	Low-medium
Belgium	Energy use (colocation and hyperscale only); IT capacity and floorspace (Belgian Digital Infrastructure Association, 2022)	Energy use estimate for colocation and hyperscale from BDIA; enterprise estimate based on IT capacity from BDIA and assumptions for utilisation and PUE based on bottom-up studies (Ademe & Arcep, 2022; Hintemann et al., 2023).	High
Bulgaria	None	Assumed to consume 2% of national service sector electricity.	Low
Croatia	None	Assumed to consume 2% of national service sector electricity.	Low
Cyprus	None	Assumed to consume 2% of national service sector electricity.	Low
Czechia	None	Assumed to consume 4% of national service sector electricity based on estimate for Poland.	Low
Denmark	Energy use for colocation and hyperscale (COWI, 2021; Danish Energy Agency, 2021, 2022a, 2022b, 2023a, 2023b).	Energy use estimate for colocation and hyperscale from Danish Energy Agency; energy use for enterprise DCs estimated based on assumptions from bottom-up studies (Ademe & Arcep, 2022; Hintemann et al., 2023).	Medium-high
Estonia	None	Assumed to consume 4.5% of national service sector electricity based on estimate for Finland.	Low
Finland	Energy use based on two-digit level industrial classification for data centres (Hiekkanen et al., 2021; Statistics Finland, 2022)	Energy use estimate for colocation and hyperscale from Statistics Finland; energy use for enterprise DCs estimated based on assumptions from bottom-up studies (Ademe & Arcep, 2022; Hintemann et al., 2023).	Medium-high
France	Energy use, IT capacity, floorspace, utilisation rate, and PUE for all data centre types (Ademe & Arcep, 2022).	Based primarily on Ademe & Arcep (2022), with optimistic (lower energy use) estimates developed using input from other country-level studies and lower utilisation and PUE assumptions.	Medium
Germany	Energy use (total), IT capacity (by size), and PUE (Hintemann et al., 2023); energy use (colocation and hyperscale) (BloombergNEF et al., 2021).	Based primarily on Hintemann et al. (2023), with optimistic (lower energy use) estimates developed using energy use estimates for large data centres from (BloombergNEF et al., 2021).	High
Greece	None	Assumed to consume 2% of national service sector electricity.	Low
Hungary	None	Assumed to consume 2% of national service sector electricity.	Low
Ireland	Electricity meter data of all sites primarily used for data centre activities (Central Statistics Office, Ireland, 2023).	Energy use data for colocation and hyperscale data centres (Central Statistics Office, Ireland, 2023); energy use for enterprise DCs estimated based on assumptions from bottom-up studies (Ademe & Arcep, 2022; Hintemann et al., 2023) adjusted for lower assumed enterprise capacity.	High
Italy	Data centre IT capacity	Estimated based on estimated IT capacity	Low-medium

Country	Available data and sources	Approach taken	Assessment quality
	(Fernandez, 2023; Politecnico di Milano, School of Management, 2022).	(Fernandez, 2023; Politecnico di Milano, School of Management, 2022) and assumptions for utilisation and PUE (Ademe & Arcep, 2022; Hintemann et al., 2023).	
Latvia	None	Assumed to consume 2% of national service sector electricity.	Low
Lithuania	None	Assumed to consume 2% of national service sector electricity.	Low
Luxembourg	Data centre IT capacity (Baxtel, 2023b).	Estimated based on IT capacity estimate from (Baxtel, 2023b) and assumptions for utilisation and PUE (Ademe & Arcep, 2022; Hintemann et al., 2023).	Low
Malta	None	Assumed to consume 2% of national service sector electricity.	Low
Netherlands	Data centre energy use (Statistics Netherlands, 2021a, 2021b); energy use and IT capacity and area (Dutch Data Center Association, 2022, 2023).	Estimated based on historical estimates from Statistics Netherlands (2017-2020) and Dutch Data Center Association (2021-2022) on energy use, IT capacity, and implied utilisation and PUEs.	High
Poland	Data centre IT capacity (Atman, 2022; PMR, 2023).	Estimated based on IT capacity estimate (Atman, 2022; PMR, 2023) and adjusted assumptions for utilisation and PUE based on other studies and countries (Ademe & Arcep, 2022; Hintemann et al., 2023).	Low-medium
Portugal	None	Assumed to consume 2% of national service sector electricity.	Low
Romania	None	Assumed to consume 2% of national service sector electricity.	Low
Slovakia	None	Assumed to consume 2% of national service sector electricity.	Low
Slovenia	None	Assumed to consume 2% of national service sector electricity.	Low
Spain	Data centre IT capacity (SpainDC, 2023)	Estimated based on IT capacity estimate from SpainDC and adjusted assumptions for utilisation and PUE based on Ademe & Arcep (2022) and Hintemann et al. (2023).	Low-medium
Sweden	Data centre energy use (Swedish Energy Agency, 2023); IT capacity (Node Pole & CBRE, 2022).	Results taken directly from Swedish Energy Agency (2023).	High

Source: JRC

3.3 Telecommunication networks

Data collection

Country-level telecommunication network energy use estimates were collected from available government sources (see 2.4 Telecommunication networks). Other relevant country-level indicators were collected from Eurostat and the ITU, including population, population density, GDP, national electricity use, industrial electricity prices, household internet access, mobile internet access rates, and mobile broadband subscriptions.

Modelling approach

Depending on the available data for a given country, different modelling approaches were used (Table 5):

- For countries with national estimates of telecommunication network energy use from reputable sources using credible methods, this was assumed to be the best available estimate. The estimate year and source are indicated in Table 5, column "National estimate year and source". Four countries (Belgium, Finland, France, Germany) are estimated using this approach, covering around 33% of mobile broadband subscriptions in the EU-27, as well as 38% of the population and 46% of GDP.

- If national energy use estimates were not available, a modelled estimate was derived using publicly available data from telecommunication network operators in that country, including corporate sustainability reports and publicly available corporate sustainability disclosures. The approximate coverage of the operator data based on publicly estimated market shares is indicated in Table 5, column "Market share covered by operator data". Total energy use was extrapolated based on the market share covered and reduced by 10% to exclude non-network energy use (e.g. data centres, offices). 19 countries were estimated using this approach, covering about two-thirds of mobile broadband subscriptions and 60% of population.

- If country-level operator data was not available for a particular Member State, we used available economic, energy, and digital indicators to derive the estimate. For example, using indicators such as electricity use per internet user or mobile connection from other similar countries. As the energy use of data networks per connection is relatively consistent across countries (after adjusting for demographic and digital factors), this approach is considered to be a reasonable estimate.

The most recent data or estimates available in most cases were from 2021. Adjustments were made based on historical trends to extrapolate these figures to generate 2022 estimates.

Table 5. Data sources and modelling approaches taken for telecommunication networks

Country	Source of national estimate	Approach	Market share covered by operator data	Quality assessment
Austria	-	Operator data	>90%	High
Belgium	BIPT (2022)	Government estimate	70-80%	High
Bulgaria	-	Operator data	60-70%	Medium
Croatia	-	Operator data	70-80%	Medium-high
Cyprus	-	Based on other indicators	-	Low-medium
Czechia	-	Operator data	60-70%	Medium
Denmark	-	Operator data	80-90%	Medium-high
Estonia	-	Operator data	>90%	High
Finland	Traficom (2022; 2023)	Government estimate	>90%	High
France	Arcep (2023b)	Government estimate	50-60%	High
Germany	German Bundestag	Government estimate	>90%	High

Country	Source of national estimate	Approach	Market share covered by operator data	Quality assessment
	(2022)			
Greece	-	Operator data	70-80%	Medium-high
Hungary	-	Operator data	>90%	High
Ireland	-	Operator data	70-80%	Medium-high
Italy	-	Operator data	70-80%	Medium-high
Latvia	-	Operator data	70-80%	Medium-high
Lithuania	-	Operator data	60-70%	Medium
Luxembourg	-	Based on other indicators	-	Low-medium
Malta	-	Based on other indicators	-	Low-medium
Netherlands	-	Operator data	>90%	High
Poland	-	Operator data	50-60%	Medium
Portugal	-	Operator data	60-70%	Medium
Romania	-	Operator data	80-90%	Medium-high
Slovakia	-	Operator data	80-90%	Medium-high
Slovenia	-	Based on other indicators	-	Medium
Spain	-	Operator data	80-90%	Medium-high
Sweden	-	Operator data	>90%	High

Source: JRC

3.4 Summary and limitations

The modelling approaches employed in this study are summarised in Table 6. The largest markets rely primarily on published country-level estimates, complemented by modelled estimates based on operator data on electricity use (for networks) and IT capacity estimates (for data centres).

Table 6. Overview of modelling approaches

Approach	Data centres		Telecommunication networks	
	Countries	Coverage	Countries	Coverage
Country-level estimates	Belgium, Denmark, Finland, France, Germany, Ireland, Netherlands, Sweden	77% of data centre capacity 46% of population 62% of GDP	Belgium, Finland, France, Germany	33% of mobile broadband subscriptions 38% of population 46% of GDP
Modelled estimate based primarily on IT capacity (data centres) or operator data (networks)	Austria, Italy, Luxembourg, Poland, Spain	19% of data centre capacity 34% of population 28% of GDP	Austria, Bulgaria, Croatia, Czechia, Denmark, Estonia, Greece, Hungary, Ireland, Italy, Latvia. Lithuania, Netherlands, Poland, Portugal, Romania, Slovakia, Spain, Sweden	66% of mobile broadband subscriptions 61% of population 53% of GDP
Modelled estimate based	Bulgaria, Croatia, Cyprus, Czechia,	4% of data centre capacity	Cyprus, Luxembourg, Malta, Slovenia	1% of mobile broadband

Approach	Data centres		Telecommunication networks	
	Countries	Coverage	Countries	Coverage
on other indicators	Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Portugal, Romania, Slovakia, Slovenia	19% of population 11% of GDP		subscriptions, population, and GDP

Source: JRC

Data centres

Published country-level estimates were available for most of the largest data centre markets covering around three-quarters of the region's data centre capacity. Country-level IT capacity data (typically covering colocation and hyperscale data centres) were used to estimate around 20% of the overall market.

Although the published country-level estimates are considered to be best-available estimates, most of the country-level estimates are modelled. Only the estimates from Ireland and the Netherlands are based primarily on measured (electricity meter) data, covering larger data centres. There are also significant uncertainties in the number and installed capacity of smaller data centres.

Telecommunication networks

For telecommunication networks, four country-level estimates were available, covering one-third of mobile broadband subscriptions. Data from operators covering the majority of each market were used to develop country-level estimates for countries covering two-thirds of mobile broadband subscriptions. Publicly reported operator data collated for this analysis accounted for around 20 TWh of electricity use, covering nearly three-quarters of the estimated total EU-27 network energy use. Only 1% of the market was modelled using other indicators.

The published country-level estimates are generally considered very robust, since they primarily rely on measured electricity data from operators (except Germany).

The main limitation of the modelled estimates using operator data stems from challenges in validating the approach used to extrapolate energy use of non-disclosing operators. In addition, this analysis assumes that 90% of operator electricity use goes to networks. This analysis also excludes energy use in diesel backup generators, estimated to be less than 2% of overall network energy use in Europe based on reported data from several operators in the region.

4. Results and discussion

4.1 Data centres

Data centres in the EU-27 used an estimated 45–65 TWh of electricity in 2022, or 1.8–2.6% of total electricity consumption. This estimate is slightly lower than Montevecchi et al. (2020), which estimated that data centres accounted for 2.7% of total EU28 electricity use in 2018.

Large data centres, including colocation and hyperscale data centres, accounted for about 65% of the total, while enterprise data centres accounted for around 35%. These shares are similar to Dodd et al. (2020), which estimated a 56/44 split in 2020 and projected a 66/34 split in 2025.

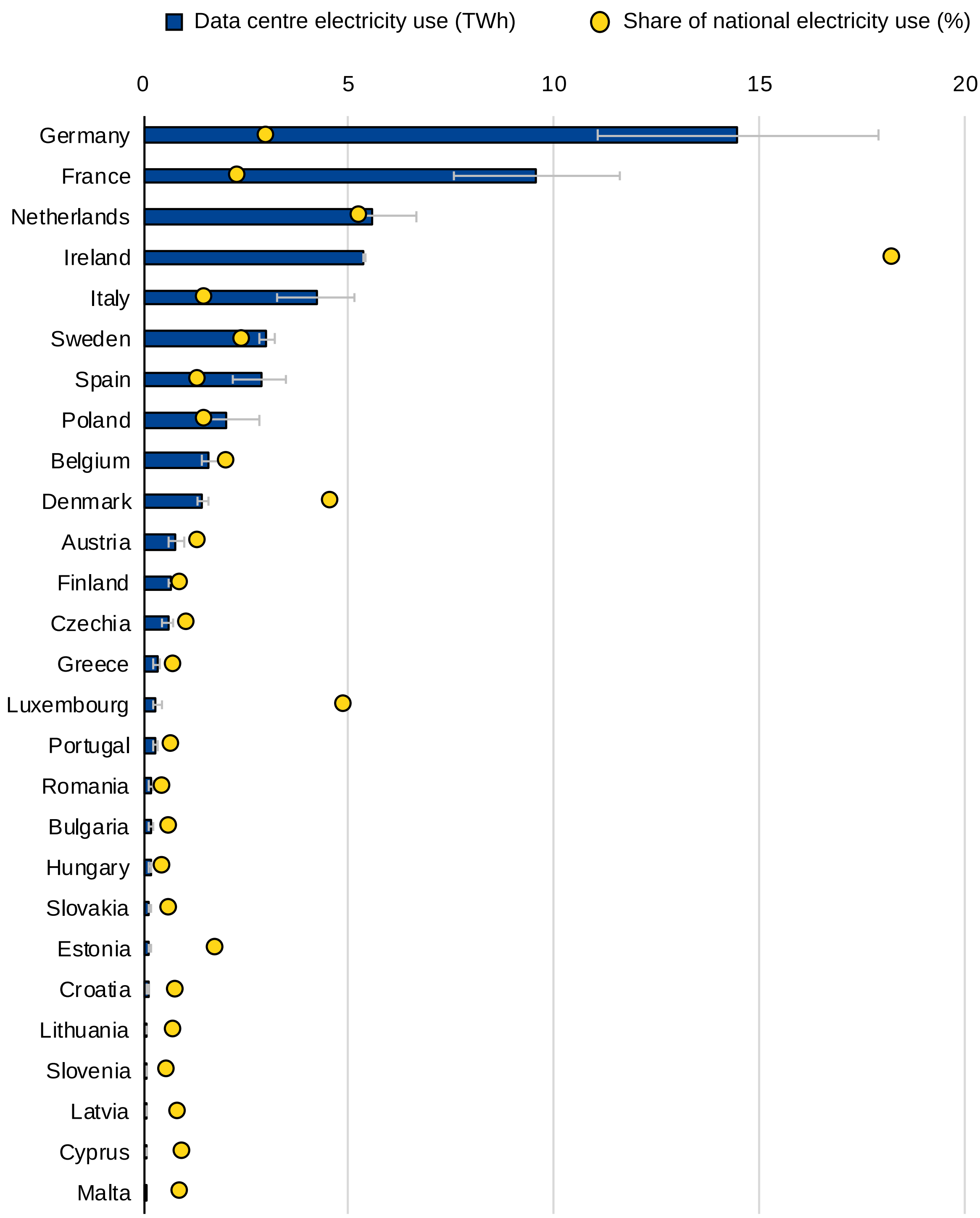
Most of the region's data centre energy use is concentrated in the largest markets. The top four data centre markets – Germany, France, the Netherlands, and Ireland – account for nearly two-thirds of the region's data centre energy use, despite having less than 40% of the population (Figure 2). The top twelve markets[7], which this study estimated based on country-level data, account for around 95% the region's data centre energy use.

In Germany, data centres used an estimated 15 TWh in 2022, equivalent to around 3% of national electricity use. In France, data centres used around 10 TWh of electricity, equivalent to 2.2% of national electricity use.

Data centres represent a significant share of national electricity use in Ireland (18%), the Netherlands (5.2%), Luxembourg (4.8%), Denmark (4.5%), and Germany (3%), Sweden (2.3%), and France (2.2%). In all other countries, data centres represent less than the EU-27 average of 2.2%.

[7] Germany, France, the Netherlands, Ireland, Italy, Spain, Sweden, Poland, Belgium, Denmark, Austria, and Finland.

Figure 2. Estimated data centre energy use by country, 2022



Note: Error bars indicate range of estimates.

Source: JRC

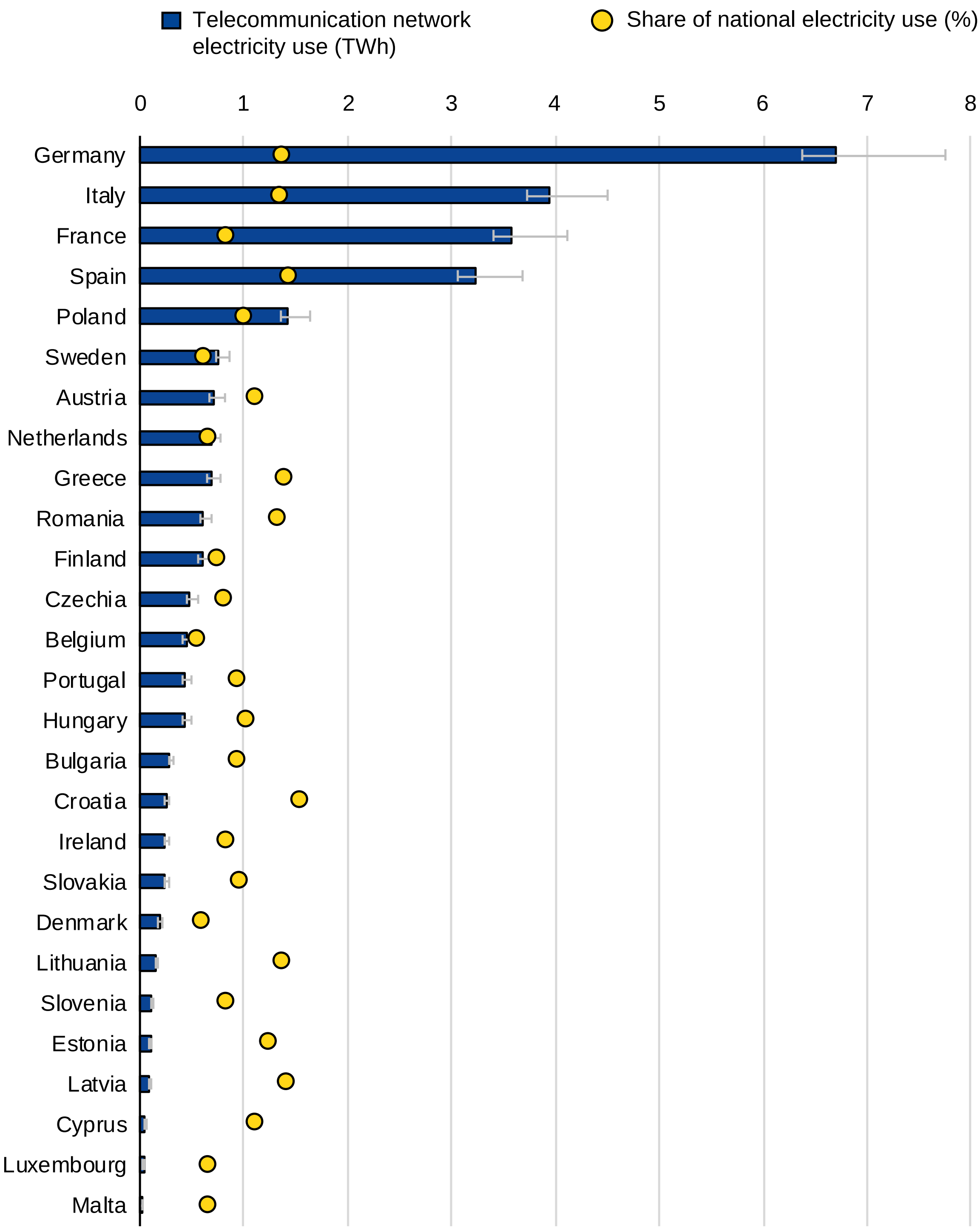
4.2 Telecommunication networks

Telecommunication networks in the EU-27 used an estimated 25–30 TWh of electricity in 2022, or 1–1.2% of total electricity consumption. Based on disaggregated data from a few countries, mobile networks likely accounted for about 60% of the total. These results are in-line with Lundén et al. (2022), which estimated 29 TWh in 2020 (EU-27), equivalent to 1.2% of electricity use.

The four most populous Member States are also the four largest users of network energy: Germany, France, Italy, and Spain (Figure 3). These four countries, representing about 58% of the population, account for 65% of the region's telecommunication network energy use.

Compared with data centres, energy use by networks as a share of national electricity use was more uniform, ranging from 0.5–1.5%. In contrast, data centre energy use ranged from as low as 0.4% in some countries to as high as 18% in Ireland. Data centres accounted for at least 2% of electricity use in eight countries, while telecommunication networks accounted for less than 2% of national electricity use in all countries.

Figure 3. Estimated telecommunication network energy use by country, 2022



Note: Error bars indicate range of estimates.

Source: JRC

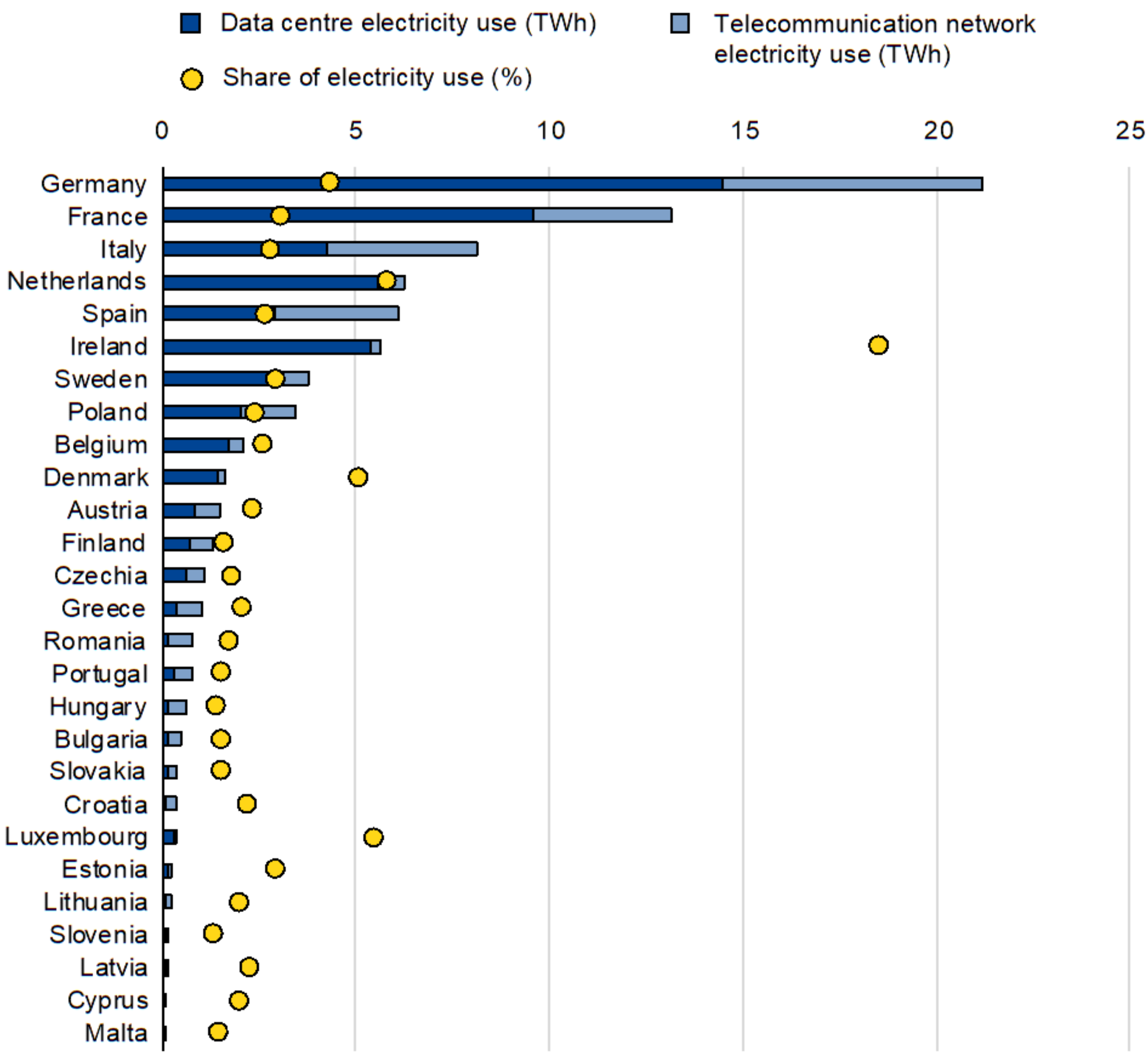
4.3 Summary

Data centres in the EU-27 used an estimated 45–65 TWh of electricity in 2022, or 1.8–2.6% of total electricity consumption. Telecommunication networks used an estimated 25–30 TWh of electricity in 2022, or 1–1.2% of total electricity consumption. The relatively wide range for data centres is indicative of the considerable uncertainty in data centre energy estimates stemming from the lack of available data.

Data centres and networks – digital infrastructure – together consumed an estimated 70–95 TWh in the EU-27, equivalent to 2.8–3.8% of total regional electricity use.

The four largest Member States by population and GDP – Germany, France, Italy, and Spain – account for about 60% of total digital infrastructure energy use in the region (Figure 4). Digital infrastructure accounts for more than 5% of national electricity use in five countries: Ireland (19%), the Netherlands (6%), Luxembourg (5.5%), and Denmark (5%).

Figure 4. Estimated digital infrastructure energy use by country, 2022



Source: JRC

5. Conclusions and recommendations

Summary

This study reviews, assesses, and uses published analyses and other public data sources to estimate the energy consumption of data centres and telecommunication networks in the EU-27 in 2022.

Data centres used an estimated 45–65 TWh of electricity in 2022, or 1.8–2.6% of total EU-27 electricity consumption. Telecommunication networks used an estimated 25–30 TWh of electricity in 2022, or 1–1.2% of total electricity consumption.

At the country level, the shares of national electricity use varies significantly for data centres, ranging from as low as 0.4% in some countries to as high as 18% in Ireland. Telecommunication network energy use was much more uniform, ranging from 0.5% to 1.5%.

While there are promising developments on data availability and transparency, notably from the largest data centre markets and telecommunication regulators in a growing number of countries, there is an overall lack of rigorous country-level data and studies available across the EU.

As digital technologies and services are evolving quickly, policymakers and companies must work together to improve data collection, quality and availability to develop more robust estimates to make informed policy decisions to manage the energy and environmental impacts of digital infrastructure.

Recommendations for future data collection and modelling

Governments and statistical agencies should develop standardised definitions and classifications. For example, developing clear definitions of what is considered a data centre, and providing criteria and guidance on classifying different data centre types. Standardised definitions and classifications are essential to compare and combine energy consumption estimates from different studies and countries.

Governments and companies should work together to improve data quality and availability to improve the quality of future estimates. For example, the following data should be collected at the country level:

- Data centre energy consumption by size and type (e.g. enterprise, colocation, hyperscale, telecom, edge, etc.);
- Telecommunication network energy consumption by type (e.g. mobile, fixed, core);
- Relevant activity indicators, e.g. fixed connections, mobile connections, mobile network coverage, network data traffic, data centre workloads (and type of tasks).

Governments, companies, and researchers should work together to develop and standardise a suite of appropriate energy intensity indicators and metrics to inform future modelling efforts. For example, energy intensity of mobile networks based on data traffic, subscriptions, and coverage area. Further work is needed to standardise measurement methodologies and indicators.

Data collection efforts should also seek to better understand energy use characteristics and implications of specific services and tasks, such as AI, streaming media, and augmented and virtual reality. Improved understanding of data centre and network energy use for specific services can help improve understanding of end-to-end energy use of specific services such as streaming video, and help prioritise measures to reduce energy use (e.g. actual impacts of lower bitrates or increased compression on networks as well as end-user devices).

Increased use of AI is likely to be an important driver of growing demand for data centre services over the coming years. AI likely accounts for less than one-quarter of data centre energy use today (Kaack et al., 2022), but the widespread adoption of AI by businesses and consumers could see this share rise (Minde, 2023). The greater use of graphics processing units (GPU) and application-specific integrated circuits (ASIC) for AI are expected to increase the power density of data centre racks, increasing cooling needs. There is a very limited understanding of AI-related energy use in data centres, including the energy use in different stages of the model life cycle (development, training, and inference), as well as the share of energy use in data centres associated with AI. Additional data from companies and methodology development from researchers is needed.

Future studies that estimate the energy use of data centres and telecommunication networks should clearly and comprehensively document and disclose data sources, assumptions, and other methodological details. The lack of available details in previous studies makes it difficult to assess the quality of analysis and compare results. Increasing the consistency of baseline data and methodologies can also improve comparability to understand energy trends over time.

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Annex

Table A.1. Overview of studies estimating the global energy use of data centres since 2018

Institution	Publications	Approach	Estimates*
Borderstep Institute	Hintemann & Hinterholzer (2020; 2022)	Bottom-up estimate based on data centre market developments (primarily in Europe), technical characteristics of servers, storage, and networking (energy use, age) and data centre infrastructure (air conditioning, power supply, UPS).	310-330 TWh in 2018 (400 TWh including crypto) 270-380 TWh in 2020 (350-500 TWh including crypto)
Ericsson; Telia	Malmodin (2020); Malmodin et al. (2023); Malmodin & Lundén (2018)	Hybrid estimate based on bottom-up estimates based on hardware shipments, complemented by benchmarking to other studies and reported company data.	220 TWh in 2015 (245 TWh including enterprise networks) 223 TWh in 2020
GreenIT.fr	Bordage (2019)	Based on the number of servers in operation and LCAs of three different data centres.	312 TWh in 2019
Huawei	Andrae (2019; 2020)	Extrapolation based on Andrae & Edler (2015) with data centre IP traffic extrapolations and energy intensity per unit of IP traffic under updated efficiency improvement scenarios.	211 TWh in 2018 196-299 TWh in 2020
International Energy Agency (IEA)	IEA (2023a) and previous versions in 2018-2022	Hybrid estimate based on the bottom-up modelling in IEA (2017), Masanet et al. (2020), and Hintemann & Hinterholzer (2022) complemented with reported energy consumption data from large data centre operators.	200 TWh in 2018 200-250 TWh in 2020 220-320 TWh in 2021
International Telecommunications Union (ITU)	ITU (2020)	Based on the modelling of Malmodin & Lundén (2018) and input from Andrae (2019).14/02/2024 15:13:00	220 TWh in 2015 230 TWh in 2020 (projection)
Lawrence Berkeley National Laboratory; Northwestern University; UC Santa Barbara	Masanet et al. (2020)	Bottom-up estimate based on shipment data for servers, drives, networking, their energy use characteristics and lifetimes, combined with assumptions for each type of data centre class and region-specific PUE.	205 TWh in 2018
McMaster University	Belkhir & Elmeligi (2018)	Extrapolation of data centre energy use estimate for 2008 from Vereecken et al. (2010) increasing by 12% per year.	704 TWh in 2017 990 TWh in 2020 (projection)
Schneider Electric	Schneider Electric (2021)	Bottom-up estimate based on workloads, data storage requirements, and global average PUE.	341 TWh in 2020
The Shift Project	The Shift Project (2019b; 2021)	Based on the model developed by Andrae & Edler (2015) with updated assumptions and scenarios.	559-593 TWh in 2017 393 TWh in 2019 (438 TWh including crypto)
University of Twente	Koot & Wijnhoven (2021)	Hybrid approach combining top-down indicators and bottom-up data (e.g. workloads per application).	286 TWh in 2016 240-275 TWh in 2020

Source: JRC

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