BloombergNEF Statkraft EATON Powering Business Worldwide

Data Centers and Decarbonization

Unlocking Flexibility in Europe's Data Centers

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Foreword: Eaton

Digitalization, in virtually every sector of Europe's economy, is driving rapid growth in the data-center industry. At the same time, Europe's energy system is being transformed through the accelerated adoption of variable renewables, prompted by steep declines in the cost of wind and solar power plants, together with government targets to decarbonize electricity generation.

The variability associated with distributed renewable generation increases the requirement from network operators for new and intelligent grid stabilization services. Data centers can help meet this need by supporting the development of a more flexible and connected energy system with their computing power and their physical infrastructure, in particular the vast amounts of battery energy storage attached to their existing back-up power systems.

This new BloombergNEF study, which Eaton is delighted to have supported, identifies and quantifies how data centers can play a meaningful role in the power sector's transition to a low-carbon future. It explores the capacity of data centers across five of Europe's largest markets - Germany, Ireland, the Netherlands, Norway and the UK - and considers how they can be part of a more open, interactive, and flexible power system. It examines the sustainability benefits that can be created by changing the status quo.

Data center facilities are unique, and comparable to microgrids in the opportunities they offer. At Eaton we believe our 'Everything as a Grid' approach can help unlock traditional thinking, assets, and systems to advance the energy transition, and we believe data centers can play an integral role. As new sustainability strategies are deployed, successful grid-interactive data centers start up across Europe, and new government legislative proposals create a vision for a more integrated and digitally-enabled decentralized energy system, we expect the findings of this new study to contextualize the enormous commercial and environmental opportunities associated with grid interactive data centers for the industry itself, and for grid operators.

With the ever-increasing demand on power, it's time for new thinking and fostering a more collaborative approach amongst energy providers and consumers. Data centers are critical to enabling Europe's new digital economy, this report shows how they can be at the heart of the energy transition, as well.

Dr. Karina Rigby

President, Critical Systems for Europe, Middle East and Africa, Eaton

Foreword: Statkraft

More renewable and less fossil-based energy is imperative to shift the global course to meet a 1.5-degree climate target. As Europe's largest producer of renewable energy, Statkraft has taken important steps together with the entire power sector to increase the share of renewables in the European power system. To further grow the share of renewables, more flexibility is needed to balance the increasing amount of variable renewable energy production.

Supply-side measures like hydropower, interconnections, batteries and clean hydrogen are part of this, as well as technological solutions to make these energy sources play well together. The demand side will also play an increasingly important role providing flexibility. As described in this report, this includes data centers, but also industrial consumers, and households via smart steering of energy consumption, flexible EV charging and distributed energy solutions

Helga Stenseth

Senior Vice President, Corporate Strategy and Analysis, Statkraft

Executive summary

3.0GW

Data center power demand in five key European markets by the end of 2021

56%

Projected variable renewable generation of total European electricity demand in 2030

16.9GW

Flexible capacity that data centers could provide to the five countries' power systems in 2030

Data centers are a core component of the 21st century digital economy, providing the critical computing and storage infrastructure that will be needed to unlock economic growth in the coming decade. At the same time, however, data centers represent a growing source of power demand, and their power usage will continue to grow over time as data creation, processing and storage needs expand.

In Europe, data-center growth is proceeding against a backdrop of rising renewable power generation as the electricity system decarbonizes. This will create opportunities not only to operate data centers from power that is increasingly clean, but also for data centers themselves to be a force for good in helping to support the power system and its transition to high renewables and low carbon.

This BloombergNEF report, authored in partnership with Statkraft and Eaton, explores the impact that data centers could have in the power system in five European countries out to 2030. It provides a projection for how great data-center power demand could be and estimates how much flexibility these data centers could provide back to the grid, in the form of demand flexibility, distributed generation and storage resources.

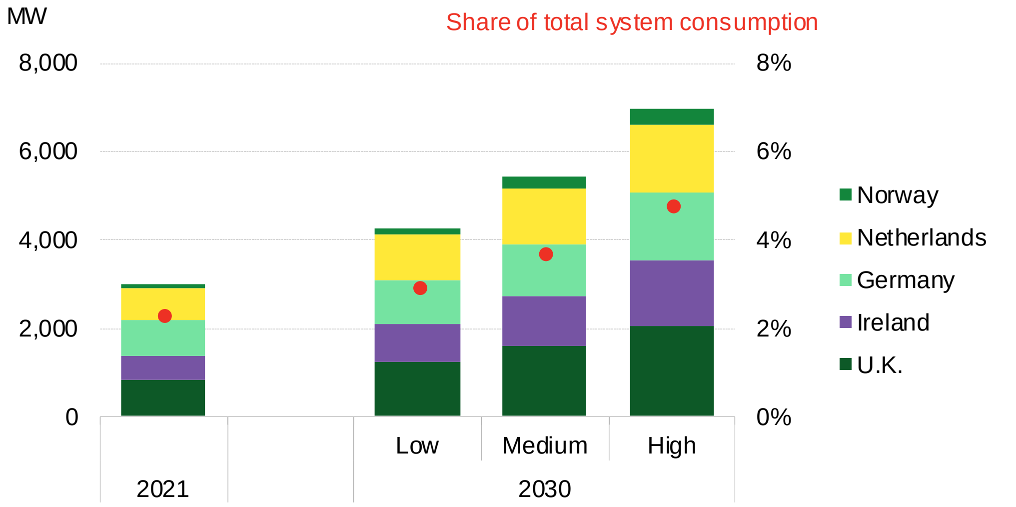
Data-center power capacity in Europe's largest markets will hit 6.9GW by the end of 2021

For the markets of Germany, Ireland, Netherlands, Norway and the U.K, hyperscale and colocation data centers will reach a total design capacity of 6.9GW by the end of 2021, and a live IT power demand of 3.0GW. We estimate that these data centers will use 26TWh of electricity in 2021, or 2.3% of the countries' total annual electricity use.

The largest owners of data centers in Europe divide into two groups: self-build hyperscale operators, such as Google and Amazon; and colocation operators, such as Equinix and Digital Realty. European data-center capacity has grown rapidly in the last two years, in part due to the coronavirus pandemic, to the point where key markets, such as Amsterdam, Dublin and London, face saturation and pushback from regulators. Seeking further growth, some data-center operators are expanding into new markets, where there is more land, cheaper power prices and easier grid connections. This includes Norway, which has seen 16% growth in data-center capacity in the past two years.

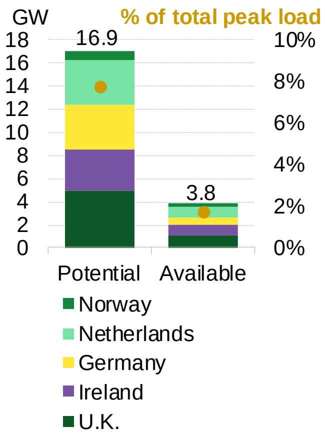
By 2030, in our medium growth scenario, data centers in the five markets rise to a design capacity of 11.9GW and a live IT power demand of 5.4GW. The 2030 capacity equates to an annual use 48TWh of electricity in 2030 – 3.7% of the countries' total annual use.

Figure 2: Data-center live IT power and share of the total annual electricity consumption of the five focus countries



Source: BloombergNEF

Figure 1: Data-center flexible capacity and share of countries' total peak load in 2030



Source: BloombergNEF

Design capacity is defined as the maximum amount of power a data center could draw if it reached its planned footprint (most data centers take years to grow as large as this initially announced capacity). This is the size of the grid connection that the data-center operator agrees with the local power provider. The 'live IT power' is the actual average power draw from the active servers installed, taking into account a utilization rate.

Variable renewables are projected to generate 56% of Europe's electricity demand in 2030, leading to a greater need for flexible resources

As data-center design capacity grows by 83% between 2020 and 2030 in the five focus countries, so does the need for greater power system flexibility. Variable renewables such as wind and solar are projected to generate 56% of Europe's electricity by 2030[1], up from 27% in 2021. This will mean greater flexibility from load centers on the grid, to better match the increasingly variable supply, to fine tune the grid for stability, and to help manage power flows on the network infrastructure. Not only will these needs become more pronounced in a renewable power system, but the conventional fossil-fuel generators used to address these flexibility issues will also become more expensive to operate. As a result, other resources, such as energy storage and demand-side management, will be needed to support the power system.

[1] Based on BloombergNEF's *European Energy Transition Outlook*, Ambitious Policy Scenario

Data centers could offer as much as 16.9GW of flexible capacity in 2030, across the five countries, aiding renewable integration

Data centers' main sources of flexibility are the uninterruptible power supply (UPS), back-up generation and in principle shifting their energy consumption by time or location. The UPS (an energy storage device) and back-up generation are there to ensure data-center operation during a grid outage. In our 2030 high growth scenario, the total flexibility that these resources could provide is 16.9GW. The different resources could be used in combination. Our analysis shows that, of this capacity, it is reasonable to assume that 3.8GW could be available for grid flexibility in 2030, based on our estimate of data-center operators' willingness to participate.

This data-center flexibility can help to stabilize the power system and integrate more renewable generation. UPS are the most sizable source of data-center flexibility and are well suited to prove frequency regulation services (which require fast response and short duration, eg, a few minutes). Data centers could offer longer-duration flexibility through shifting compute tasks to other times of the day or to other data centers, aligning with times and places of greater renewable generation. On-site generators could also be a large source of flexibility. While most of this capacity is diesel today, and therefore too emissions-intensive to run except in an emergency, lithium-ion batteries or hydrogen could replace diesel generation in the medium term.

Table 1: Data-center resource flexibility potential assessment

	UPS	Time shifting	Location shifting	Back-up gen	Back-up battery
Target application(s)	Ancillary services, eg, freq. regulation	Energy markets	Energy markets	Energy markets	Energy markets, and system services
Present in data centers?	Yes, very common	Load is present but shifting is not	Load is present but limited shifting	Yes, very common, mostly diesel	No, still in pilot stage
Power capacity available	Full, equiv. to data-center capacity	30%-50%	30%-50%	Full, equiv. to data-center capacity	Full, equiv. to data-center capacity
Energy capacity available	Available for only a few minutes	Hours – task must be completed by a specific time	Hours – based on compute capacity in data centers	2-8 hours, depends on stored fuel	Up to 50%
Likely willingness to adopt	High, depends on battery type	Low to med, easier for hyperscale operators	Operator must run multiple data center sites	More likely for low-carbon fuel. Concern for reliability	Additional revenue is vital to business case

Source: BloombergNEF

The barriers to broad adoption of data-center flexibility are significant

Data-center operators' main goal is to serve customers with reliable computing power. For many of them, offering flexible capacity to the power grid jeopardizes this, either through poorer computation performance or a less reliable service. While there are definite economic, regulatory and climate benefits to data-center flexibility, these are not well understood and there are no government signals that currently incentivize most data-center operators to take this perceived risk. New and hyperscale built data centers are the most likely to engage with flexibility, compared with existing and colocation-operated sites.

Data-center operators in Europe are exploring new flexibility resources for data centers

While the widespread use of data-center flexibility is limited, there are examples of early adopters today in Europe. Several data-center operators use or plan to use their UPS to provide grid services, such as Microsoft, DigiPlex and BaseFarm. Many data centers already shift compute tasks due to operational limits or cost advantages. Google and Microsoft furthered this application with their aim to match electricity use with renewable energy at an hourly level, though these applications are still developing. Colocation provider Iron Mountain has launched a similar product that would allow its customers to track their renewable energy use hour-by-hour. There are also a few initial projects for battery and hydrogen fuel cells as backup generation. The large hyperscale operators typically lead in these new approaches, similar to how they led in the use of renewable power purchase agreements. They also have the benefit of being their own computing customer (eg, Facebook or Google), which may make it easier to experiment.

Regions outside of the largest markets might become future hubs of green data-center development

Most European data-center capacity is in five cities: Frankfurt, London, Amsterdam, Paris and Dublin (FLAP-D). The data-center industry is often called a victim of its own success, as it has experienced pushback on further development in these markets due to pressure on local resources, such as power network capacity and land availability. In 2019, the Amsterdam area saw a year-long ban on new data-center build, followed by several policies dictating new data-center locations and total capacity. Frankfurt is looking at similar policies. Ireland is a more extreme case where besides network constraints, Eirgrid, the Irish system operator is concerned data centers endanger the security of supply and the country's carbon-emission targets.

These developments have encouraged data-center operators to look to new regions to develop projects. The Nordics is one region of interest for data-center developers, where the cold climate suits data centers. Norway's clean and cheap power supply, thanks to its large hydro generation capacity, is attractive to data-center developers. The country's limited fiber connections and distance from dense populations are challenges that the Norwegian government is addressing.

Countries keen to attract data-center investment should pay attention to the rampant development in the FLAP-D countries. Managing data-center development thoughtfully will avoid the need for the types of corrective policies seen in the Netherlands and Ireland.

Table 2: Comparison of data-center development factors, by country

	Power grid emissions (gCO2/kWh)	Industrial power prices (euro/MWh)	Power grid reliability (SAIDI, hours)	Current data-center power consumption (% of total)	BNEF data-center growth forecast to 2030 (%)
Germany	350	148	0.25	1.2%	88%
Ireland	316	97	0.8	14.2%	104%
Netherlands	390	75	0.78	5.4%	80%
Norway	11	20	1.5	0.5%	205%
U.K.	230	160	0.28	2.6%	93%

Source: BloombergNEF. Note: Colors indicate favorability towards further data-center development.

Data-center flexibility has clear benefits, but more work is needed to quantify and communicate them

Data-center operators could capture several benefits by providing flexibility services to the grid:

- Financial: operators can reduce or offset energy costs by optimizing energy use against energy prices and network charges, or providing paid flexibility services to the system operator
- Environmental: reduce carbon emissions from own operations by aligning energy use with renewable generation, or displace the use of fossil fuel generation for system and network flexibility needs
- Connections: grid connections with agreed flexibility may enjoy cheaper and quicker connection times due to less infrastructure reinforcement needed
- Pre-empt regulation: data centers are large loads and further build-out could put strain on the power system, leading to regulatory intervention. Acting pre-emptively and reducing this power system strain through flexibility can offset this need for intervention
- "Green" products: customers are becoming more aware of climate change and seek new products. Low-carbon products due to flexibility measures could be a competitive advantage

Currently, these benefits are either not easily quantified and measured, or do not accrue directly to data-center operators and their customers. Over time, governments could design suitable regulations and incentives to quantify and realize these benefits, if they are to encourage data center participation in grid services

New forms of service level agreements could overcome one of the larger obstacles to data-center flexibility

Data-center operators and their customers have clear service level agreements (SLAs), which lay out the performance expectations of the computing service. These include latency, processing speed, uptime and storage capacity. Service level agreements are a key sticking point preventing colocation data-center operators from considering adopting greater flexibility. Re-examining their design could allow more operators to participate in power market flexibility. This would require the buy-in of customers. This change might start with big tech and cloud customers, which make up a significant portion of Europe's data-center customers and have their own decarbonization goals. Aligning SLAs with the climate goals of this large customer base might accelerate data-center flexibility.

Improving market signals could encourage data-center operators to act

Many data-center operators and users are not incentivized to act flexibly. Signals, such as cost and carbon emissions indicators, might encourage data-center operators to participate and help to integrate renewable into the power system. Data-center operators could charge users varying energy prices throughout the day to reflect power market conditions, for example charge cheaper prices at night when demand is low and wind output is high. Many energy suppliers already offer so called time-of-use tariffs to residential and commercial customers. While time-of-use tariffs would incentivize cost efficiency, grid carbon intensity signals would also benefit carbon efficiency.

Exposing data-center users and software engineers to these signals would encourage design of software and applications to be flexible. Ultimately, software engineers would design applications to be delay-tolerant or respond to real-time market signals.

Trials and pilot projects are needed to understand the potential of flexibility

Data-center operators have little experience with power system flexibility and need to build confidence in the concept. A series of trials or pilots would explore the potential capacity within data centers, and address concerns about the impact on performance. Information sharing and collaboration between all the parties involved would be key to build awareness within the industry. There are many lessons to learn, such as which party is at risk, who is responsible and who benefits. This may also require some sandboxing or ring-fencing to avoid breaching existing commercial contracts and service-level agreements.

Section 1.

European data center market 2021–2030

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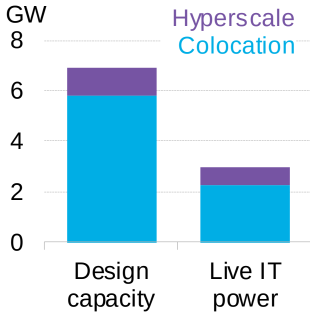
Section 1. European data-center market 2021-2030

Most data-center capacity in Europe is in five countries: Germany, the U.K., France, Ireland and the Netherlands. More specifically, this capacity is almost all in five cities, called the FLAP-D markets: Frankfurt, London, Amsterdam, Paris and Dublin. These markets are the largest for a variety of reasons. Firstly, Frankfurt, London and Amsterdam have some of the largest internet exchanges, including The London Internet Exchange (LINX), DE-CIX in Germany, and AMS-IX in the Netherlands, exchanging huge volumes of traffic. Dublin is a data center hub, particularly for hyperscale and self-build data centers. This is due to several reasons including a history of large technology companies headquartering in Ireland, a mild climate and a large wind resource. Other reasons for the size of these markets include the historic availability of large areas of land to build on, available grid connections, regulatory flexibility, a skilled workforce and demand for computing services.

Figure 3: Data-center capacity in 2021 in five focus countries



Source: BloombergNEF

This report focuses on data-center markets in the U.K., Ireland, Germany, the Netherlands and Norway. We chose these regions as they either have significant data-center capacity (eg, U.K. and Netherlands), are currently facing or will face strains on the power grid due to data-center growth (eg, Ireland), or have the potential to accommodate green and flexible data centers (eg, Norway). By the end of 2021, we expect the data center 'design capacity' across these five countries to be around 6.9GW, split 25:75 into hyperscale and colocation. Of this 6.9GW, 3.0GW is 'live IT power' (ie, the average power draw of the data-center servers) – see glossary below.

In this chapter, we explain the market dynamics of data centers in Europe, show our estimate of 2021 data-center capacity and electricity demand, and display a range of low, medium and high growth forecasts for 2030. We focus on hyperscale and colocation data centers, excluding distributed telecoms computing and private enterprise data centers, such as those owned by banks or hospitals.

Data centers glossary

Data center: A purpose-built server farm, hosting computing capacity. Data centers are either owned and operated by a company for its own computing needs (termed in this work a 'self-build') or they are owned by 'colocation' providers – having built the data center for the purpose of leasing space to clients.

Colocation: A data center built for the purpose of renting space for servers and other computing hardware to clients. Colocation data centers provide the building, cooling, power and bandwidth. If they are retail colocation data centers then they also provide the computing infrastructure.

Hyperscale: Often referred to as 'self-builds', these data centers are owned and operated by cloud service providers, such as Amazon Web Services and Microsoft Azure, or by technology companies such as Facebook and Apple.

Private data centers: Not covered in this research, private data centers tend to be owned by only one company for their personal use, built on the site of the company premises. While many companies have moved to 'the cloud' (which rely on colocation and hyperscale data centers) banks, governments and healthcare companies still own a lot of private data-center capacity.

Design capacity (MW/GW): The announced capacity of a data center in megawatts – usually the maximum grid capacity that the data center has been permitted access to by the grid operator. Data centers' true power demand practically never matches this design capacity.

Installed IT power (MW/GW): The installed power capacity of a built, active, data center in megawatts. This takes into account the data-center footprint actually built (which is less than the design capacity), how much of the built space is leased (vacancy rate) and how much of the leased space structure is filled with computers (termed 'rack capacity'). This 'installed' figure, while not reflective of actual power draw, is an important figure for our flexibility analysis in Section 3, as data center back-up systems (such as uninterruptible power supply (USP), back-up generators) would typically be sized according to this metric. This value also covers the peripheral power uses such as air conditioning and other IT equipment.

Live IT power (MW/GW): The average power draw of a built, active, data center. This takes the installed IT power figure, and reduces it to reflect how many of these racks are typically on (live rack capacity) and then how many of those are typically in use (utilization rate).

Utilization rate (%): The average utilization of the installed servers in the data center, over the year. Utilization rates tend to be highest for the hyperscale facilities, compared to colocation operators.

1.1. European data-center market dynamics

In Europe, the data-center market has been growing at around 12% CAGR[2] for the last few years, driven by increased demand for computing and by a rapid migration of many business processes to the cloud. Where computing has historically been done on smaller decentralized servers or private data centers, much of it is now in the cloud. This chapter reviews the main players in the European data-center market and explains how the commissioning process works.

Data-center operators and their partners

While there are over 2,000 data-center operators in Europe, this report focuses on the largest operators, specifically big technology firms and colocation companies (Table 3). The largest colocation operators in Europe are Equinix, Digital Realty, China Telecom and NTT Communications.

Table 3: Example operators and their major European locations

Type of data center	Example data-center operators	Main markets	Utilization rates of installed servers	Live IT power across all five countries, 2021 (GW)
Hyperscale	Google, Apple, amazon, facebook, Microsoft	Dublin, Amsterdam (emerging), London (emerging)	90-92%	0.7
Colocation	LUMEN, EQUINIX, DigiPlex, NTT, IRON MOUNTAIN, DIGITAL REALTY	Frankfurt, Berlin, London, Amsterdam, Paris, Dublin	64-80%	2.3

Source: BloombergNEF. Note: utilization rates are applied after lease and rack capacity rates to determine the extent to which data-center servers are being used.

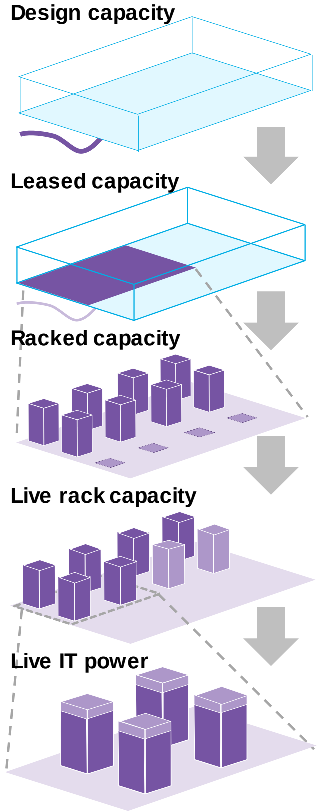
2 Compound annual growth rate, ccording to Iron Mountain

Commissioning a data center involves a variety of partners. The process varies depending on the data center requirement, the operators, the location and the country. Much of the early process (land procurement and permits) is managed by a real-estate firm, such as CBRE, JLL or Knight Frank. These companies either act on behalf of a data-center operator or are acting speculatively based on expected data-center demand. In today's market, it is common for data-center operators to begin sourcing new sites once their existing halls are 80% leased.

Commissioning a new data center

Many customers will want access to computing capacity within a few weeks, however, it can take up to four years for a data center to be built, from announcing the plans through to being fully operational (Figure 5). The better the operator can plan its pipeline, and the more accurately it can meet commissioning timings, the more likely it will be to guarantee the capacity is sold just before, or when, it comes online.

Figure 4: Data-center capacity assessment



Source: BloombergNEF

Assessment, planning permission and design: The developer of a new data center is usually a real-estate company. The company must first select a site and have a design plan. It must then obtain planning permission and a permit to connect to the power grid. To do this, a 'design' capacity for the site must be submitted (Figure 5). This is larger than what is actually built but does provide operators with the option for future expansion. The grid operator commits to reserving this amount of power grid capacity for the data-center operator, even if not used. Permits for water, gas and internet connection must also be procured. From the planning application, to the announcement, to building the first data hall can take around a year. However, this first stage can be much longer if the grid operator does not have the ability to connect the data center site to the grid for years (as is the case in Ireland today).

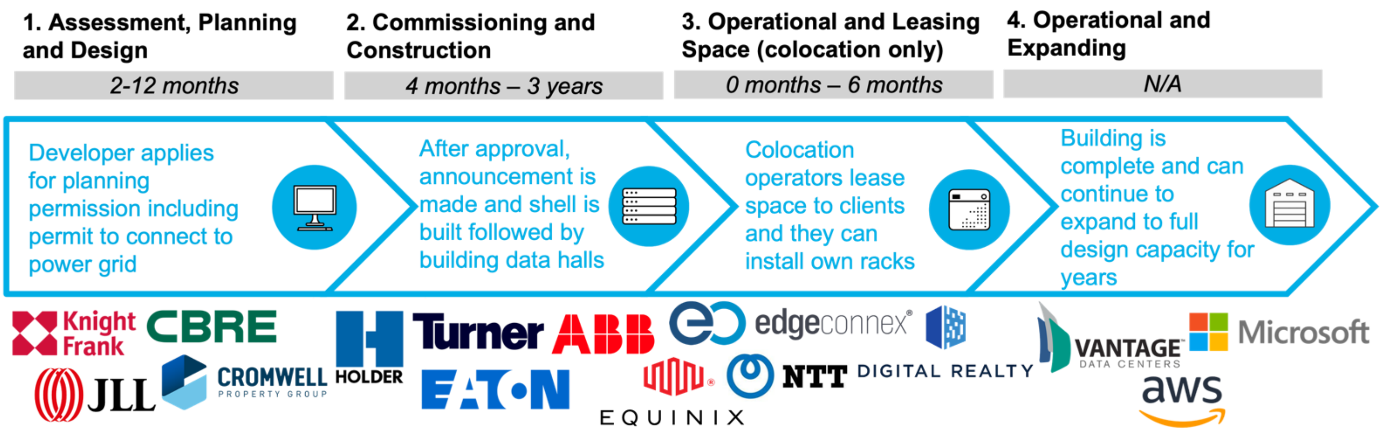
First phase of commissioning: Once planning permission has been approved, the next step is to build the 'shell' – a watertight building/hall. Generally, large data-center sites comprise of a few data halls, turning the 'shell' into a 'fitted' space. A 10MW data center may, for instance, have five data halls of 2MW each. To commission a data hall involves building the structure, installing floors, lighting, cooling, security systems etc., and then installing computing racks, uninterruptible power supply (UPS) and back-up power. Depending on customer demand, the first phase of data center commissioning could be as little as 5% of the design capacity power (often the case for smaller data centers) or close to 100%, in the case for technology self-builders. At this time, the data-center owner will start buying backup power capacity. They tend to match it to the number of installed computers they expect online in the coming months (rather than oversizing it to the design capacity).

Leasing space: For colocation operators, the next step is to lease out space to clients. In markets with strong computing demand, leases are being signed before the data hall is even commissioned. Most leases are signed before the operator has installed computing racks, either because the client wants to install the racks themselves, or because the operator trusts it will get the racks in before the client actually needs them. When space is leased, computers are then installed, and the process begins of connecting them to the internet and to a power source. The amount of leased space that has computers installed is called 'rack capacity' and then amount of those computers actually turned on and ready to be used is 'live rack capacity'. As more space is leased, and as more racks are built out, the data-center owner will procure more back-up power.

Expansion: The larger operators tend to start building more data halls, planning site expansion, or applying for planning permission for new data-center sites, when their existing servers are 80%

leased. It may take two years for a large colocation data-center site to scale to an 80% lease rate, although in the past 18 months demand for cloud computing has been so high that it is common now for new data centers to be fully leased before they are even complete. This means the rate of data-center expansion in 2020 and 2021 has been much higher than previous years.

Figure 5: Timeline of data-center build and example players



Source: BloombergNEF. Note: company logos are reflective of example companies who are active at each stage of the process.

1.2. Hyperscale and colocation data-center capacity, 2021 and 2030

In this chapter, we provide a bottom-up market sizing for data centers in the U.K., Germany, Ireland, the Netherlands and Norway, for 2021 and 2030. We also outline some current market trends that have guided our market sizing work.

Data-center power demand, 2021-2030

Data centers in the five markets (colocation and hyperscale) will have a total design capacity of 6.9GW by the end of 2021, and a live IT power demand of 3.0GW (Figure 6). By the end of 2030, we calculate that this will rise to a design capacity of 11.9GW and a live IT power demand of 5.4GW (Table 4), with the U.K. having the largest data-center market. We expect U.K. live power capacity to reach 1.6GW under our medium scenario while Norway reaches roughly 0.3GW – both regions experiencing high growth.

A massive amount of new capacity announced in the last two years is due to come online over the next few years, allowing us to build a bottom-up market sizing for 2024. To get to a 2030 forecast, we applied CAGRs for each country, for 2024-2030. These were based on market trends in hyperscale and colocation data centers, and on European policy/regulation. The growth rates for data-center capacity in the U.K., Ireland, Germany and the Netherlands are relatively similar as these are mature markets. The growth rate in other European countries (including Norway) is much higher, because they are starting from a small base and because these 'Tier 2' markets is where many data-center operators told us they foresee the majority of new-build.

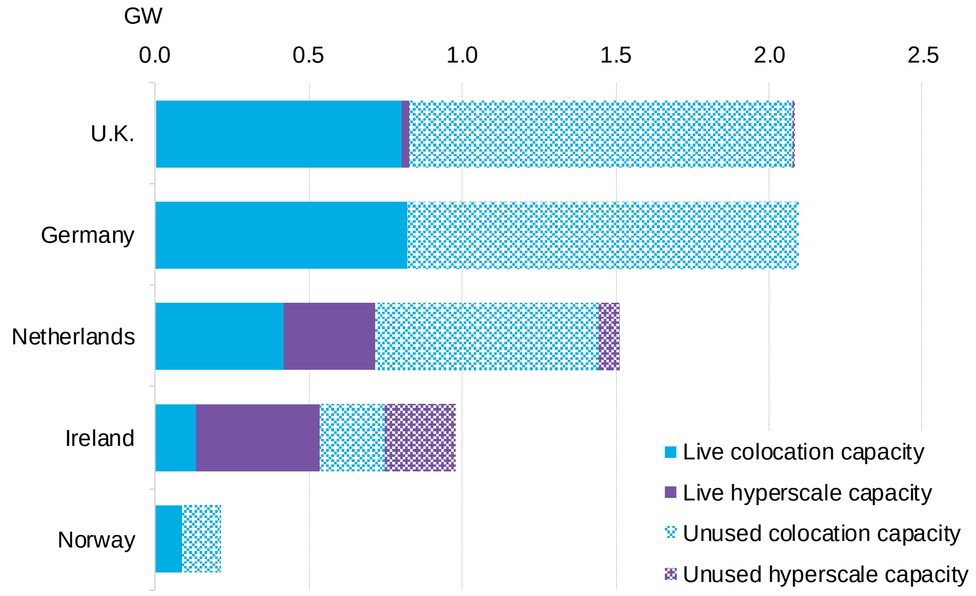
Table 4: Hyperscale self-build and colocation data-center capacity and power demand, 2021 and 2030

Location	2021 capacity (GW)		2021 power demand (TWh)	2030 capacity, medium scenario (GW)		2030 power demand (TWh)	% of 2030 total power demand	Dominant type of operator
	Design	Live IT power		Design	Live IT power			
U.K.	2.1	0.83	7.2	3.7	1.6	14	5%	Colocation*
Germany	2.1	0.82	7.2	2.9	1.2	11	2%	Colocation*
Netherlands	1.5	0.72	6.3	2.6	1.3	11	8%	Colocation
Ireland	0.98	0.54	4.7	2.2	1.1	10	24%	Hyperscale
Norway	0.21	0.09	0.7	0.51	0.26	2.2	2%	Colocation*

*Source: BloombergNEF, European power market regulators. Note: 2021 capacity is expected capacity by December 2021. 2030 numbers taken from 'medium' scenario (see Figure 3). *'Colocation' denotes a region with less than 100MW of hyperscale data-center capacity, and therefore mostly colocation. 2030 electricity demand numbers for each country were taken from various regulators from each region.*

While the U.K. and Germany predominantly host colocation operators today (over 95% of live IT power is colocation versus hyperscale), we expect the U.K. to grow its hyperscale data centers over the next few years. This follows the trend in the Netherlands, whose growth in the last two years has been mainly due to hyperscale self-builds across the region. This includes Google's new 130MW data center in Middenmeer and Microsoft's planned data center in Hollands Kroon – both outside of Amsterdam.

Figure 6: European data-center power capacity, 2021



Source: BloombergNEF

Data-center electricity demand, 2021-2030

Table 5: Data-center electricity demand, as a % of national demand (TWh)

Country	2021	2030
U.K.	3%	5%
Ireland	15%	24%
Germany	1%	2%
Netherlands	6%	8%
Norway	<1%	2%

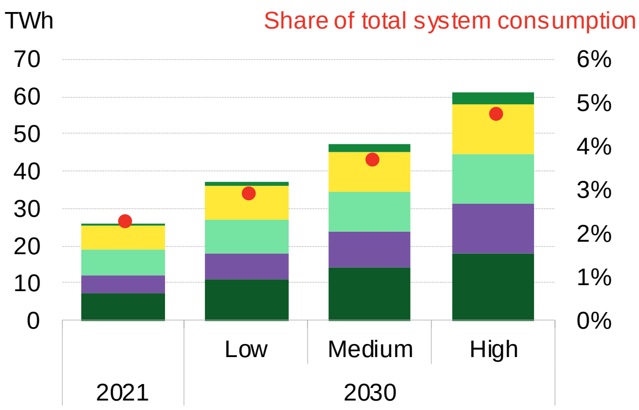
Source: BloombergNEF. Note: '2030 %' is using our medium scenario.

We expect data centers in these five countries to consume 26.2TWh of electricity in 2021, growing to 47.6TWh in 2030 (medium scenario). Data centers in the U.K. and Germany consume the most in 2021, however, by 2030 we expect data centers in Ireland to consume 24% of national electricity demand for the year, compared to just 2% in Germany (Table 5). Data centers in Norway, the U.K. and Netherlands will consume 2%, 5% and 8%, respectively, of their nation's electricity demand in 2030.

This level of electricity consumption is significant for all countries. For comparison, BNEF's latest Long-Term Electric Vehicle Outlook projects that electric vehicles could be responsible for around 4% of Europe's electricity demand in 2030, or 6% in Germany, in the 'Economic Transition Scenario'. In other words, data centers may warrant at least as much attention as electric vehicles when it comes load management and impacts on the power network.

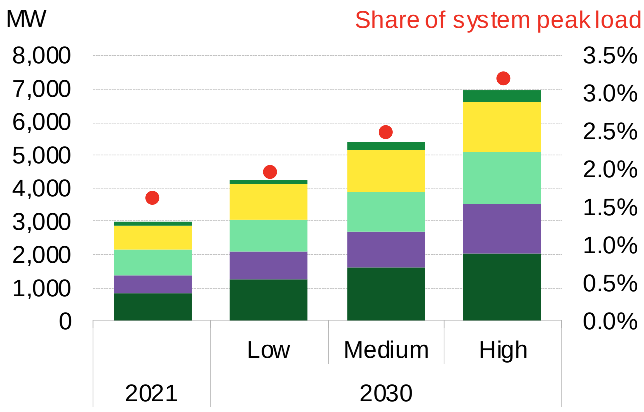
However, this level of growth is not set in stone, and there is considerable uncertainty on how data centers in Europe will grow. For the 2030 forecast, we built three scenarios – low, medium and high growth. These scenarios assume different compound annual growth rates (CAGRs) to reflect uncertainties regarding planning permission, constrained land options and available power connections. Ireland's growth is the most uncertain within the five countries (we flex it between 4% per annum in the low scenario to 9% in the high scenario), as the country prepares to undertake new data-center regulations. Norway is a young data-center market and the government is actively encouraging data-center growth. We therefore expect a boom in Norway's data-center market in the next 10 years, growing at 6.5% CAGR from 2024-2030 (in the medium scenario).

Figure 7: Data-center electricity demand for five focus countries under growth scenarios



Source: BloombergNEF

Figure 8: Data-center live IT power for five focus countries under growth scenarios



Source: BloombergNEF

Looking across all five markets in aggregate, our projections show that data-center electricity demand could reach 3-5% of total power demand by 2030. Live IT power could be 2-3.5% of peak load in aggregate by 2030.

Methodology

Many public reports and companies publish estimates of data-center power capacity, and future growth. The reports differ based on the type of data centers included and different assumptions on utilization rate, rack capacity and lease rate – sometimes called the 'vacancy' rate. Some reports use a standard utilization rate across hyperscale and colocation data centers, while some reports consider differences between type of data center and region. In this estimate we differentiate between countries and between the type of data-center operator. We have used high utilization rates for both hyperscale and colocation operators because of the significant demand for computing power in Europe, and because so much recently leased capacity is being used by large cloud and technology companies (which reportedly have almost 100% utilization rate).

- **2021 design capacity.** Our estimates start from information collected by Eaton on Europe-wide data-center capacity and announcements, as of January 2020. To create a capacity estimate for 4Q 2021, BNEF collected public announcement data for hyperscale and colocation expansions and new-builds for 2020 and 2021, in MW. Where the announcement implies the data center will be built in phases, reaching beyond December 2021, we estimated a scaled MW capacity. For data centers that did not announce their MW capacity we estimated this based on known MW capacity of similar data centers. This end-of-year figure we refer to as '2021 design capacity'. This is the total capacity that we believe will have obtained planning permission, a power connection, and has the time to have been built by December 31, 2021.
- **Live IT power capacity.** This is the amount of power we believe data centers actually draw, on average, over the year. To calculate this, we applied specific rack capacities and lease rates to the design capacity numbers, to get installed IT power. Then, we applied live rack capacities and utilization rates to achieve live IT power capacity. These assumptions differed between hyperscale and colocation providers, and also differed between regions. For example, across all hyperscalers, we assumed lease rates of 100%, rack capacity rates of 90% and utilization rates of 91%. In Ireland, we assumed hyperscalers have rack capacity rates of 70%. For colocation providers in the U.K., we assumed a 68% lease rate, 80% rack capacity rate and 74% utilization rate. In the Netherlands we assumed a 68% lease rate, 70% rack capacity rate and 79% utilization rate. These assumptions were based on variables such as data-center efficiency, age, location, design and speaking to operators themselves to understand actual demand.
- **A note on 'installed IT power' capacity:** While this section, focuses primarily on live IT power, since this is the best measure of actual power draw for data centers, the 'installed IT power' figure is important for our later calculations on how much flexibility a data center could provide to the grid. This is because back-up power systems (UPS, back-up generators) would typically be sized for the higher 'installed' figure.
- **2021 electricity demand.** To calculate the electricity demand in TWh we multiplied the live IT power by the hours in the year.
- **2024 forecasts**. We began with a bottom-up estimate for 2024 design capacity, using a combination of announcements and assumptions about new build. For large hyperscale announcements that will come online over multiple years, we assumed a portion of these would come online in 2024. For the low growth scenario, we assumed Ireland's grid regulator will block certain data-center build, and that the U.K. grid operator will reject planning permission for larger data centers in built-up areas. For the high growth scenario, we assumed all planned data centers will be built to their maximum design capacity. We also created a live IT power demand estimate for 2024, by assuming lease rates, rack rates and utilization rates for each country.
- **2030 forecasts.** From 2024 to 2030, we applied low, medium and high CAGRs for each country based on extensive research, tracking growth trends in adjacent industries, data on historical data-center growth and research calls. For example, we applied a 4.5% CAGR for

the U.K. in our medium scenario, based on data on land bought by hyperscalers, growing procurement of renewable energy sources and new hubs opening across London and Manchester. For the U.K.'s high growth scenario the CAGR rises to 6.5% for colocation operators and 9% for hyperscalers, based on new land that we assume is bought for large technology companies to house their data centers.

Recent market trends

Recent growth has been driven by cloud computing demand: There has been significant data-center growth in Europe between 2019 and 2021 (Table 4). Overall, the five markets have grown at an average 12% CAGR from 1Q 2020 to 4Q 2021. This additional 532MW of new supply in the last 24 months was driven by colocation providers including Equinix, Digital Realty, Proximity, NTT and Iron Mountain, as well as new hyperscale data centers. Most customers signing new colocation leases in the past 18 months have in fact been big tech and cloud companies, whose own growth has been too rapid to meet with hyperscale self-build sites, leading them to lease space from colocation operators.

Table 6: European data-center capacity CAGR from 4Q 2019 to 4Q 2021 (expected)

Country	Colo	Hyper-scale
U.K.	2.3%	11%
Ireland	11%	5%
Germany	3.4%	0%
Netherlands	0.7%	24%
Norway	7.7%	0%

Source: BloombergNEF

Market constraints have made longer-term planning necessary: The data-center market in Europe faces severe supply challenges in sourcing computing equipment, land and network capacity, yet it has continued to meet high demand. The constraints have ultimately led more customers (especially hyperscale operators) to plan a few years ahead for new data-center build or expansion. These public announcements of future data-center build are the foundation of BNEFs year-end 2021 capacity calculations, and our 2024 capacity estimates.

Most new-build has been site expansion, not new sites: Dublin, London, Amsterdam and Frankfurt are mature data-center markets and the large operators there have shown little interest (or ability) to buy brand new sites. Instead, they have focused on expanding current sites. For example, NDG and Vantage's Newport-based 70MW data center in the U.K. recently announced plans to double this current capacity. Equinix just finished its 44,000 square foot expansion of its seventh Amsterdam location in April 2021, which will add 6-20MW of capacity to the existing data center. This trend is as true for colocation sites as it is for hyperscale, meaning that grid operators should expect to see more applications to expand power capacity at existing connections, than for entirely new permits.

Table 7: National peak power load forecasts, and data center demand as a % (installed IT power)

Country	2030 peak load (GW)	Share of peak load
U.K.	58	2.7%
Ireland	6.6	17%
Germany	104	1.2%
Netherlands	20	6.2%
Norway	28	0.9%

Source: BloombergNEF, Entsoe

New-build capacity announcements are not reliable, leading to many varied market size estimates: The listed design capacity in public announcements is not always reliable. Many of these 'announced' data centers do not end up getting built, or do not build their full capacity. Additionally, data center lease, rack capacity and utilization rates can differ between region, type of operator, age of datacenter and time period. All of these variables make it difficult to calculate the electricity demand for European data centers, and accounts for the vastly different estimates across public reports.

M&A activity in the colocation industry continues to drive data-center demand: Market consolidation in Europe continues to increase as large colocation providers seek to expand into other markets. Recent large transactions include GTT's acquisition of Interoute for $2.3 billion and Iron Mountain's acquisition of EvoSwitch NL. In July 2021, DigiPlex, a leading Nordic developer, was acquired by IPI Partners, a deal that will close in 3Q 2021. The motivation behind these acquisitions is to gain a better position across Europe, and leverage more control over equipment suppliers and customers by increasing their capacity and reach.

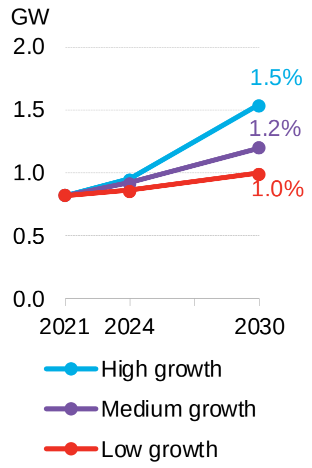
1.3. Country profiles

This section provides country level details and analysis on data-center growth.

Germany

There are strong parallels between Germany and the U.K. Both have data-center industries almost entirely comprised of colocation data centers (95%), and both have strong central regions in financial capitals (Frankfurt and London), with smaller data center regions in secondary cities. While it seems that big technology self-builders are more eager to expand into the U.K., we do not expect the same level of growth for technology companies to build data centers in Germany. However, in 3Q 2021, Google indicated interest in creating a new facility in Frankfurt and launching a new cloud region in Berlin-Brandenburg. The company plans to invest 1 billion euros in 'digital infrastructure and clean energy' in Germany – reflected in our 2030 high growth scenario. In our high growth scenario to 2030, 205MW of new supply for hyperscale data centers is added, assuming 168MW of this will be 'live' in 2030. This is due to companies such as CloudHQ and Logistics Parks, announcing future plans for building hyperscale data centers – although nothing has been built yet.

Figure 9: Germany data-center growth forecast, for live IT power and % of peak load in 2030



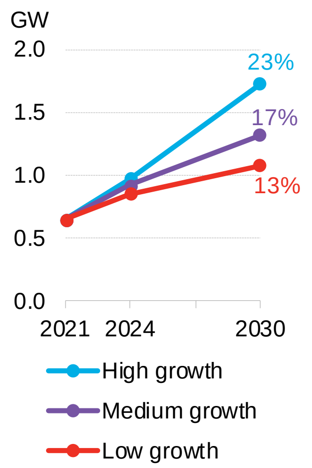
Source: BloombergNEF.

In contrast, Germany's colocation industry is very active. The German data-center market has seen new entrants in 2020 such as Vantage and Trusted-Colo that clearly see value in German expansion – most likely due to its power grid connections and the internet. Companies including Vantage, NTT, Colt, CyrusOne and Iron Mountain dominate the market in Germany, stimulating a lot of recent M&A. For example, Penta Afra has now made two strategic acquisitions of data centers in Dusseldorf and Hamburg, proving that Frankfurt is not the only hub in Germany. In the last two years, the colocation data-center market's design capacity grew at a CAGR of 3.4%. We assume this trend will continue although the growth is more likely to be in areas outside of Frankfurt, such as the Rhine and Brandenburg. Our medium growth forecast to 2030 is a 4% CAGR, and a 7% CAGR for the high-growth scenario.

Ireland

Ireland is generally reported as hosting the most hyperscale data-center capacity, being the location of most big-tech company data-center capacity in Europe. It houses the data centers of AWS, Google, Microsoft, Apple and Facebook. We expect an additional 124MW of design capacity to be constructed between 4Q 2019 and 4Q 2021 with a further 524MW to be built by 2024 (Figure 10, median scenario). Of this growth, 40% is for hyperscale and 60% is for colocation operators. Ireland boasts excellent subsea cable links/connectivity landing points that transfer data to international locations such as the U.S. It is also English-speaking and has a skilled workforce, making it an attractive choice for U.S.-based technology companies.

Figure 10: Ireland data-center growth forecast, for live IT power and % of peak load in 2030



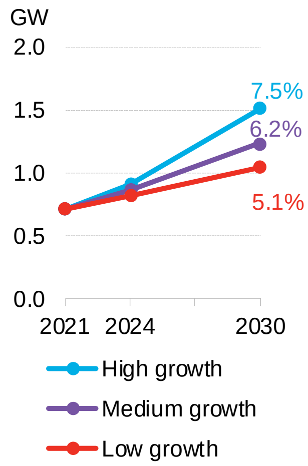
Source: BloombergNEF.

Equinix, one of the largest data-center operators in Europe, recently finished constructing a new 100MW+ data center in Dublin that has already been pre-leased to a hyperscaler, while Echelon recently won planning permission for another site in Dublin that will eventually bring Echelon's total capacity in Ireland to 500MW. We estimate that 15% of Ireland's electricity demand is now for data centers, and because of this there are concerns about the impact of data centers on grid resilience. This percentage increases by 2030 to 18% (low), 24% (median) and 31% (high). Our scenarios are in line with the system operator's, Eirgrid, estimate that data centers in Ireland could account for 23% of country's total electricity demand by 2030.

Growth in Ireland may not be as rapid as it has been in the past few years, reflected in our low-growth scenario. This is due to factors such as Ireland's recent policy proposals that include limiting new data center build unless flexibility requirements are met, and pushbacks from Irish citizens who are concerned about power and climate issues. Unlike Germany, most data centers in Ireland are in one major city – Dublin. Dublin's electricity grid was not built to cater for such high demand from data centers, which has resulted in network supply constraints. In June 2021, the Commission for Regulation of Utilities (CRU) proposed that the Irish network operators, Eirgrid and ESB Networks, prioritize data-center connection requests outside of network constrained areas – creating uncertainty for the future of 30 proposed data centers in and around Dublin. The grid operators would prefer data centers to be built in the west of the country where network and renewable capacity is more plentiful, rather than Dublin's congested network on the eastern coast.

Netherlands

Figure 11: Netherlands data-center growth forecast, for live IT power and % of peak load in 2030



Source: BloombergNEF.

The Netherlands' growth in the last two years has been propelled by the hyperscale sector, due to its attractive tax structure, cheap electricity, and strong internet and grid connections. The successful growth of the fintech market in the Netherlands may also have a connection – with over 430 companies active in the industry. Microsoft and Google have built large data centers outside of Amsterdam, in places such as Middenmeer and Groningen. Amsterdam also houses data centers from colocation providers such as Interxion and EdgeConnex – two of the largest players in the Netherlands – and many operators have plans to expand current sites including NorthC and Equinix in Rotterdam and Amsterdam.

Compared to Germany and the U.K., the Netherlands has a more balanced combination of colocation and hyperscale data centers, split almost equally between the two. By the end of 2021, the Netherlands will have around 1.5GW of design capacity, with 710MW being used, resulting in data centers being responsible for around 6% of the Netherlands' electricity (Figure 11). This electricity consumption remains relatively flat until 2030, with data-center electricity consumption increasing from 7% to 8% in our medium growth scenario. We foresee growth reaching 1.2GW of live IT power in 2030 (Figure 11), split by 693MW for colocation and 563MW for hyperscale operators.

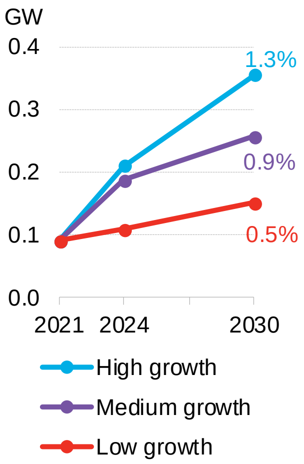
In 2019, data-center build was paused due to extreme growth leading to larger pressures on the electricity grid, particularly in Amsterdam. In 3Q 2020, this break was lifted and data centers were allowed to start building again. However, to gain approval, data centers must have a PUE (power usage effectiveness) of 1.2. PUE can only be this low if the data centers have a very high utilization rate. This energy efficiency requirement is reflected in the higher utilization rate assumptions in our 2030 calculations for the Netherlands.

Norway

As it becomes increasingly difficult to source new land and reliable, low-carbon power in the largest European data-center markets, 'Tier 2' data-center markets will likely expand. A search for new data-center hubs, along with Norway's reputation for having the highest proportion of renewable energy in Europe, makes the Nordic country an attractive new destination for data-center operators.

In June 2021, a new industry body, the Norwegian Data Centre Industry, was set up to help grow Norway's data-center business. It comprises large colocation operators such as Green Mountain and DigiPlex, which have both pioneered Norway's data-center industry, having collectively announced over 100MW to be built between 2020 and 2024. Since then, the Norwegian

Figure 12: Norway data-center growth forecast, for live IT power and % of peak load in 2030



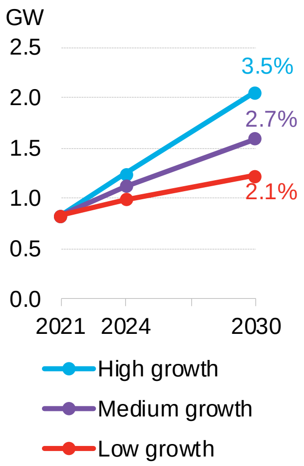
Source: BloombergNEF.

government has published a strategy for sustainable data centers and announced it invested $300 million in new data centers in 2019 and 2020. This government push is one of the factors influencing our medium (8.5%) and high (11%) growth scenarios for 2030 for colocation data centers.

Currently, Norway has around 200MW of design capacity, with around 84MW of live IT power, resulting in data centers being responsible for less than 1% of Norway's electricity consumption. We expect this to increase to 2% (2.3TWh) in our 2030 medium-growth scenario (Figure 12). In our high-growth scenario we assume ongoing support from the Norwegian government, further expansion of current DigiPlex, Green Mountain and Bulk data centers (which have collectively expanded on their sites by over 15MW in the last few months alone), and increasing interest from colocation operators. This high-growth scenario brings Norway to 716MW of design capacity in 2030 (Figure 12), and 356MW of live IT power. Norway's low-growth scenario assumes a stagnant market in Norway with only three or four local colocation players and no hyperscale customers or international investment. This could happen if internet connectivity is more of an issue than operators initially thought, and the large data-center operators decide they do not want the cost and complexity of opening entirely new sites outside of their current markets.

U.K.

Figure 13: U.K. data-center growth forecast, for live IT power and % of peak load in 2030



Source: BloombergNEF.

Of the five regions, the U.K. is projected to have the largest data-center build in 2030 across all three growth scenarios (Figure 13), as well as the highest data-center electricity consumption. The majority of data centers in the U.K. are colocation facilities, with 802MW of live power (and cloud companies leasing space from these operators). There is currently only around 25MW of live power owned by hyperscalers. We expect hyperscale design capacity to grow in all three 2030 scenarios, with an extra 131MW in our low growth scenario, 386MW in our medium growth scenario and 596MW in our high growth scenario. This high growth assumption is based on new build from cloud companies such as Microsoft and AWS, which have both indicated plans to build in the U.K. AWS recently was approved for an 84MW data center while Google bought land last year in June 2020, presumably for new data-center build.

Colocation operators Equinix, Virtus and Ark have all opened new data center facilities in the last six months in the U.K., each with plans to expand and/or build new data centers in London. Within Europe, London is the largest data center hub. Colocation operators are building in the U.K. for many reasons including the size of London's financial center, and the size and reach of London's fiber capacity. Connectivity in the U.K. is among the best in Europe.

We apply a CAGR rate from 2024-2030 for colocation operators of between 2.5% and 6.5% for 2030 in the U.K. These rates are in line with adjacent industries as well as historical data-center growth, and take into account Covid-19 effects and planned build. Under our high growth scenario, which assumes significant hyperscale supply is built in the U.K., we predict around 2GW of live IT power by 2030, which is our highest estimate across Europe. This would result in data centers being responsible for 5% of the U.K.'s electricity consumption, doubling, from 3% in 2021.

Section 2.

Flexibility in the future power system

Section 2. Flexibility in the future power system

The growth of data centers is taking place against a backdrop of rapid, far-reaching change in the power sector. Renewable power generation has had a break-out decade both in Europe and globally, with costs falling dramatically and penetrations rising year after year. Variable renewables – wind and solar – are now understood to be the primary means by which the power sector will reduce (and eventually eliminate) its greenhouse gas emissions.

However, power systems were not designed for the variability of solar and wind power, and there is now a greater need for flexibility in the system to manage this increased variability. This flexibility will serve multiple purposes and comes from a variety of sources all along the power value chain, from generation to demand.

Put simply, new sources of flexibility are needed to help achieve greater deployment of renewables and reduce carbon emissions. These new sources will come in part from new technologies such as utility-scale energy storage, but also from the demand side, which has historically not engaged with flexibility needs. While in the past, power generators had to lift or reduce production levels to match demand, in future, major sources of demand will also be 'flexed' – meaning reduced, increased, or deferred to another time – to help accommodate changes in renewable energy production.

Table 8: Data-centers electricity demand, as a % of national demand, 2021 and 2030

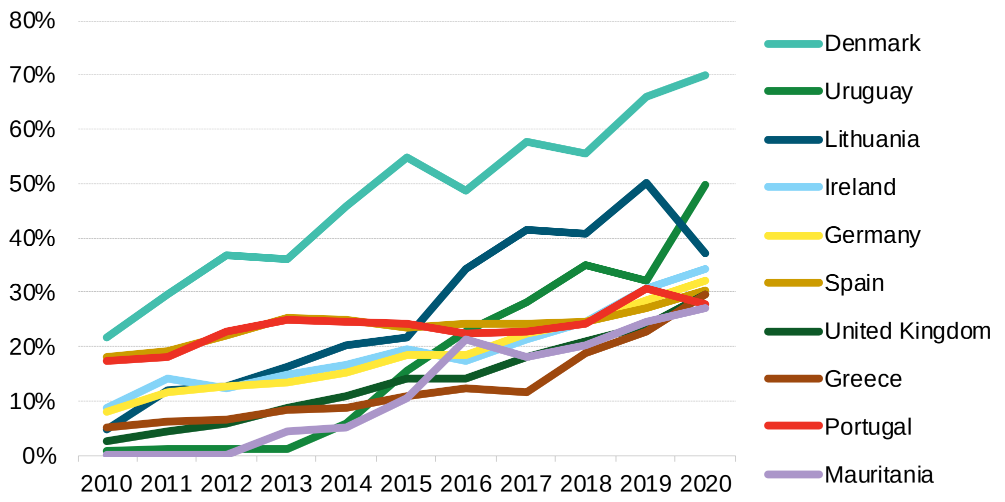
Country	2021	2030
U.K.	3%	5%
Ireland	15%	24%
Germany	1%	2%
Netherlands	7%	8%
Norway	<1%	2%

Source: BloombergNEF. Note: '2030 %' is using our medium scenario.

As detailed in the previous section, data centers are a significant portion of demand that is expected to grow. The European Commission estimates that data centers accounted for 2.7% of electricity demand within the EU and expects this to reach 3.2% by 2030. Our own estimates, re-shown here in Table 8 indicate that individual countries could have higher penetrations than this.

All of this means that data centers have an opportunity to play a meaningful, helpful role in the power sector's low-carbon transition. They have a range of on-site resources that could serve flexibility needs: they represent large loads that could be used for demand response, and often have on-site batteries and generation that are rarely put to use. Data centers can use these resources for flexibility, but operational, contractual and regulatory barriers limit participation.

Figure 14: Leading nations' wind + solar penetration rates (share of annual power demand)



Source: BloombergNEF.

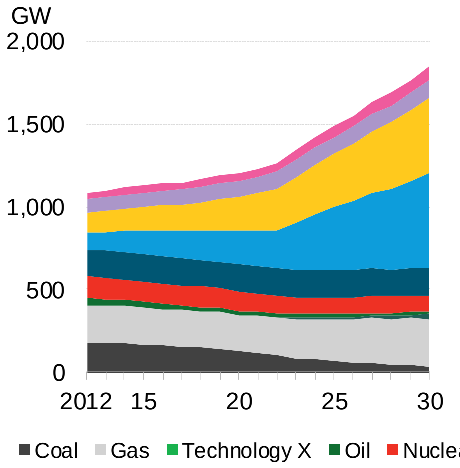
2.1. Europe’s decarbonization ambitions require more renewables, and more electrification

The European Union aims to reduce carbon emissions by at least 55% by 2030 (from 1990 levels) and to achieve carbon neutrality by 2050. Norway and the U.K. have also put in place ambitious climate pledges. Solar and wind are crucial to these ambitions and many countries are already reaching high levels of renewable generation in their power systems, producing more than 30% of annual electricity generation. European countries feature strongly in the global top-10 for wind and solar penetrations (Figure 14).

The deployment of renewable generation will accelerate in European power systems. The Ambitious Policy Scenario[3] in BloombergNEF’s *European Energy Transition Outlook* (web | terminal) shows renewable capacity increasing to 1,160MW by 2030, up from 580MW in 2021 (Figure 15). Over the same period, the proportion of variable renewable electricity generated more than doubles, from 27% to 56% (Figure 16).

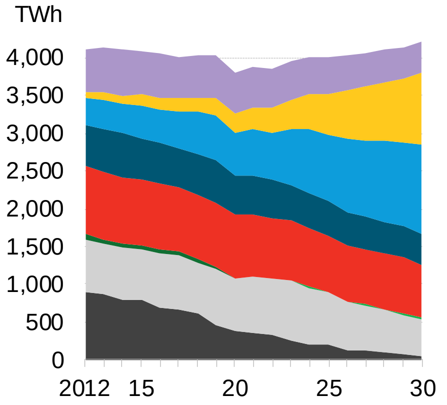
At the same time, parts of the economy will ‘electrify’ – switch from burning fossil fuels to using electricity – including transport, heating and industrial processes. In our Ambitious Policy Scenario, this trend of electrification increases power demand by 16% above general demand in 2030 (Figure 17). The operation of the power system will benefit as a whole if this new electrified demand can flex and align with the output from renewables.

Figure 15: European power capacity by technology



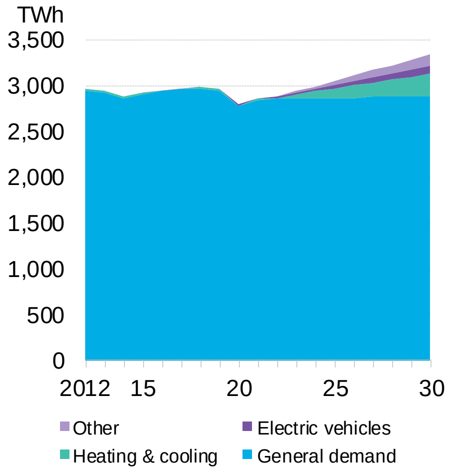
Source: BloombergNEF European Energy Transition Outlook, Ambitious Policy Scenario

Figure 16: European power generation by technology



Source: BloombergNEF European Energy Transition Outlook, Ambitious Policy Scenario

Figure 17: European electricity demand by origin



Source: BloombergNEF European Energy Transition Outlook, Ambitious Policy Scenario

[3] The Ambitious Policy Scenario puts Europe’s energy sector emissions on a pathway compatible with increased 2030 targets and net-zero by 2050. Here we only show the trajectories as far as 2030, but further electrification and uptake of hydrogen drive decarbonization in the years beyond.

2.2. The need for flexibility

With more electrification, and higher renewables penetrations, comes a greater need for flexibility. We categorize the need for flexibility into three areas: energy markets, system services and network management, as detailed in Table 9. The scale of a power system's flexibility needs depends on a range of factors, such as the generation mix, demand profiles, network topology and the region's environmental conditions.

To meet power system needs, flexibility plays a role over different timeframes. Looking ahead days, weeks and even years, there must be enough supply to meet demand, while in the short-term, system operators fine-tune grid resources to maintain the system frequency on a second-to-second basis. For networks, it means planning and building infrastructure for grid conditions years in advance and ensuring in real time that voltage and thermal conditions stay within operational parameters.

Table 9: Grid flexibility needs

	Energy markets	System services	Network management
Description	From hour to hour, energy supply and demand must match. In a high-renewables world, variations in wind and solar mean other generators, storage assets and demand sources will have to flex to match.	The system operator contracts for services with various stakeholders to ensure that the power system as a whole is reliable and operates at its nominal frequency (50Hz in Europe). Typically referred to as 'ancillary services'.	Network operators must manage the flow of power on their networks so that power supply is reliable and at the lowest cost for grid users. This includes managing voltage levels on the lines and fault levels on infrastructure.
Buyer	Energy retailers Power traders	System operator	Transmission system operator Distribution system operator
In a more renewable power system	• Greater variability from hour to hour, day to day and week to week • Daily net load profiles see steeper ramps up and down • Dispatchable plants operate at lower turn-down levels, and must ramp up and down (expensively) • Peaks are shorter • Resource adequacy to the fore – ensuring enough generation when needed	• Dispatchable plant are fewer or lower proportion of the generation fleet so less reserves as backup, and less inertia available to maintain frequency • Greater variability in generation, potentially more prediction error • Different resources will be needed for 'black start' – restarting the power system following a total power outage.	• More wires needed to move energy from one area to another • Greater variation in generation can cause voltage and reactive power issues • Changing power flows on networks • Irregular and extreme power network situations

Source: BloombergNEF

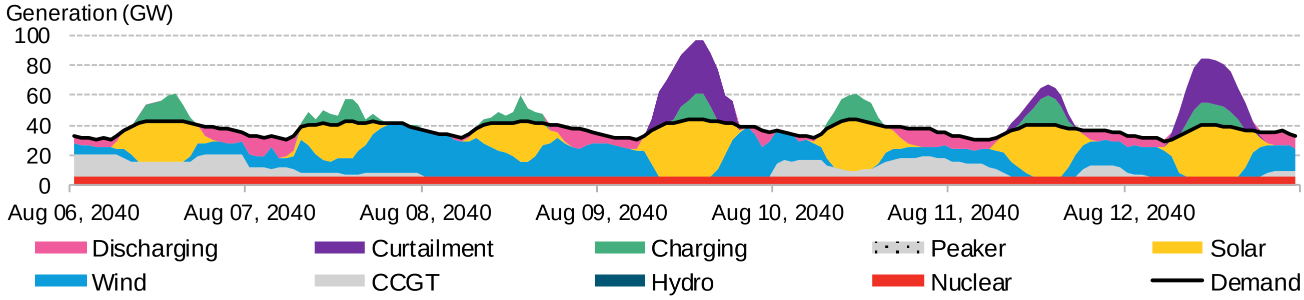
2.3. The future need for flexibility

As renewable generation grows and eats into the market share of dispatchable thermal generation, there will be growing flexibility needs across all three areas.

Energy markets

From hour to hour, the supply and demand of power must be matched. Trading in the wholesale energy (power) markets serves as the main avenue for this matching to occur, with generators, traders and retailers adjusting positions both in the day-ahead and intraday. Fundamentally, as wind and solar grow, there will be greater variability in 'net load' – the energy demand that needs to be met after wind and solar have been netted off from demand. This will manifest as periods when wind and solar meet all (or almost all) of demand, and other periods when they meet very little demand. And there will also be times when the system swings quickly from one of these conditions to the other (see Figure 18). This means all other resources: dispatchable generation, energy storage and flexible demand, will need to adjust their output accordingly.

Figure 18: Power supply and demand in a week with typical levels of renewable output in 2040, U.K.

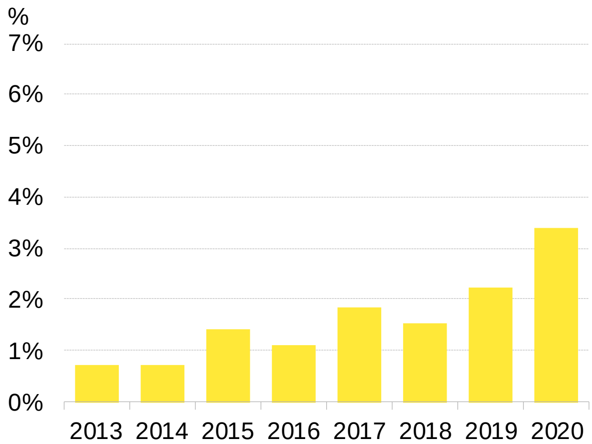


Source: BloombergNEF. Note: from 2018 BNEF-Eaton-Statkraft study, Flexibility Solutions for High- Renewable Energy Systems: U.K. Pink and green 'discharging' / 'charging' are for energy storage. CCGT = combined-cycle gas turbine; peaker = peaking gas.

In Europe, the capacity of dispatchable plant will remain roughly constant over the next decade, but these plants will be run less often (Figure 21). The reduced running time and fast ramps means that dispatchable generators will become more expensive to run, per unit of energy produced. This creates opportunity for new resources such as energy storage and demand-side flexibility, to help match electricity supply and demand.

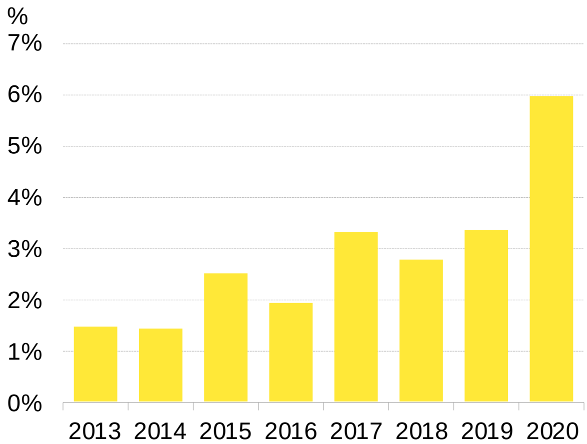
Aside from providing reliability, new resources like storage and demand-side flexibility will also help absorb more renewable energy, and reduce emissions by limiting the use of fossil-fueled generation. Already, in Germany power prices are negative for 3% of the hours in the year in the day-ahead market (equivalent to five hours per week), and nearly 6% of hours in the intraday market. These are visible signs of growing renewables impacts, a lack of flexibility in the system, and an opportunity for power loads that can flex to absorb more clean energy.

Figure 19: Negative power price hours in the year, Germany day-ahead market



Source: BloombergNEF

Figure 20: Negative power price hours in the year, Germany intraday market



Source: BloombergNEF

System services

System operators (the entities responsible for managing a nation or region's power system) procure a range of services to ensure the stability and reliability of the grid. These services have historically been provided by power generators as a small top-up to their main revenue stream of selling energy – hence they are often referred to as 'ancillary services'. These are paid-for services that sit outside of the mainstream traded power markets, and typically serve one of these goals:

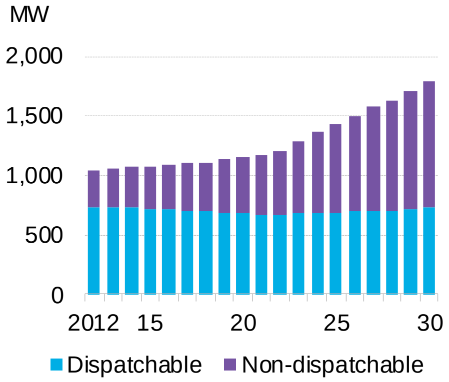
- Regulate and maintain the system frequency (and voltage) within a narrow band
- Correct short-term (eg, sub-hourly) imbalances between supply and demand, typically a result of forecast error or production errors
- Provide reserves (or back-up) for unexpected contingencies, eg when a power plant or transmission line trips offline
- Other services, such as black-start (restarting the grid after a major outage) or reactive power

Payments are structured so that providers get a fee for injecting or withdrawing small amounts of energy at the right moment, often at quite short notice (can be sub-second to sub-hour). In some cases, there are additional payments for being on standby to provide these services, usually paid per MW for a period of time. Capacity mechanisms are another form of system services, contracted on a very long-term basis (eg, one-year contracts, awarded up to four years ahead) to provide reliability during the most challenging periods of the year.

Many of these services come from conventional thermal power plants, and as these operate less frequently in future, system operators will turn to new resources to deliver them.

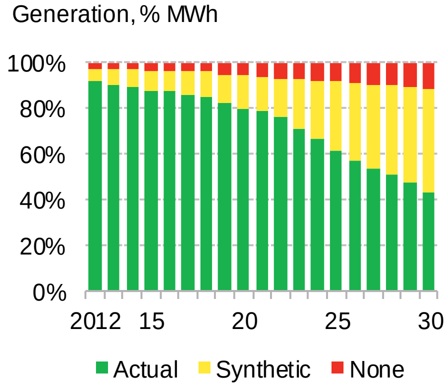
Some of these system needs may grow in future. One particular issue is falling levels of inertia, or synchronous generation, connected to the grid, which helps to keep the grid operating at a frequency of 50 hertz. Inertia typically comes from spinning thermal generation, which has fallen from 92% of all generation in 2012, to 79% in 2021 and will decline to 44% by 2030 (Figure 22).

Figure 21: Dispatchable power plant capacity in Europe



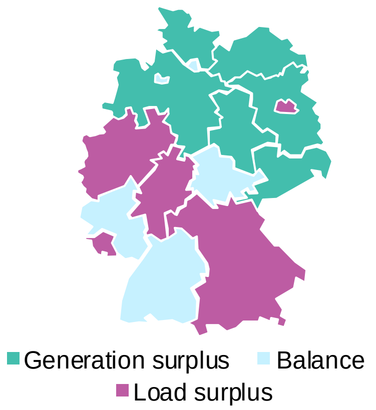
Source: BloombergNEF European Energy Transition Outlook 2021

Figure 22: Percentage of inertia-providing generation in Europe



Source: BloombergNEF European Energy Transition Outlook 2021

Figure 23: Expected energy balance in Germany, 2030



Source: BloombergNEF

Thermal generators have historically provided inertia as a by-product but in the future, system operators will have to seek (and likely pay for) other sources of inertia or increase the amount of frequency regulation resource available. Batteries are one of the most likely technologies to help address the inertia challenge. Wind turbines have the potential to provide ‘synthetic inertia’, which means that turbines program their power inverters to emulate a synchronous spinning generator.

Network management

Flexibility can help management network issues such as congestion, which occurs when power plants and traders want to move energy produced in one part of the power network to a demand center elsewhere, but energy flows on the grid are already ‘maxed out’.

Network congestion can manifest on the distribution network as an overloaded distribution substation, or on a high-voltage transmission line for the bulk movement of electricity from one region to another. Managing and reducing these situations can reduce the required investment in grid infrastructure, improve network efficiency and reduce curtailment (wastage) of renewable energy.

In Germany, there is a mismatch between where renewable energy is plentiful in the windy north, and where demand is high in the industrial and populated south (Figure 23). This mismatch has led to renewables curtailment, as well as unscheduled flows of electricity into neighboring countries, and back into Germany via other routes. Network build-out takes years due to design and planning requirements, and often faces local opposition.

2.4. Sources of flexibility

To complement conventional power plants, system operators are now exploring new sources of flexibility, including batteries (both utility-scale and small-scale), renewable power plants and flexible demand, also known as demand response. The latter can take various physical forms, from major industrial loads that can be curtailed, to more distributed opportunities such as electric vehicles or electric water heaters that can operate in a way that is responsive to grid conditions.

Figure 24 lays out the capabilities of different grid resources to provide different types of flexibility. Conventional resources can provide a range of flexibility services, but their future development is limited. The new flexible resources are still small relative to conventional resources and efforts are ongoing to increase their participation, both in volume and ability to participate in flexibility services.

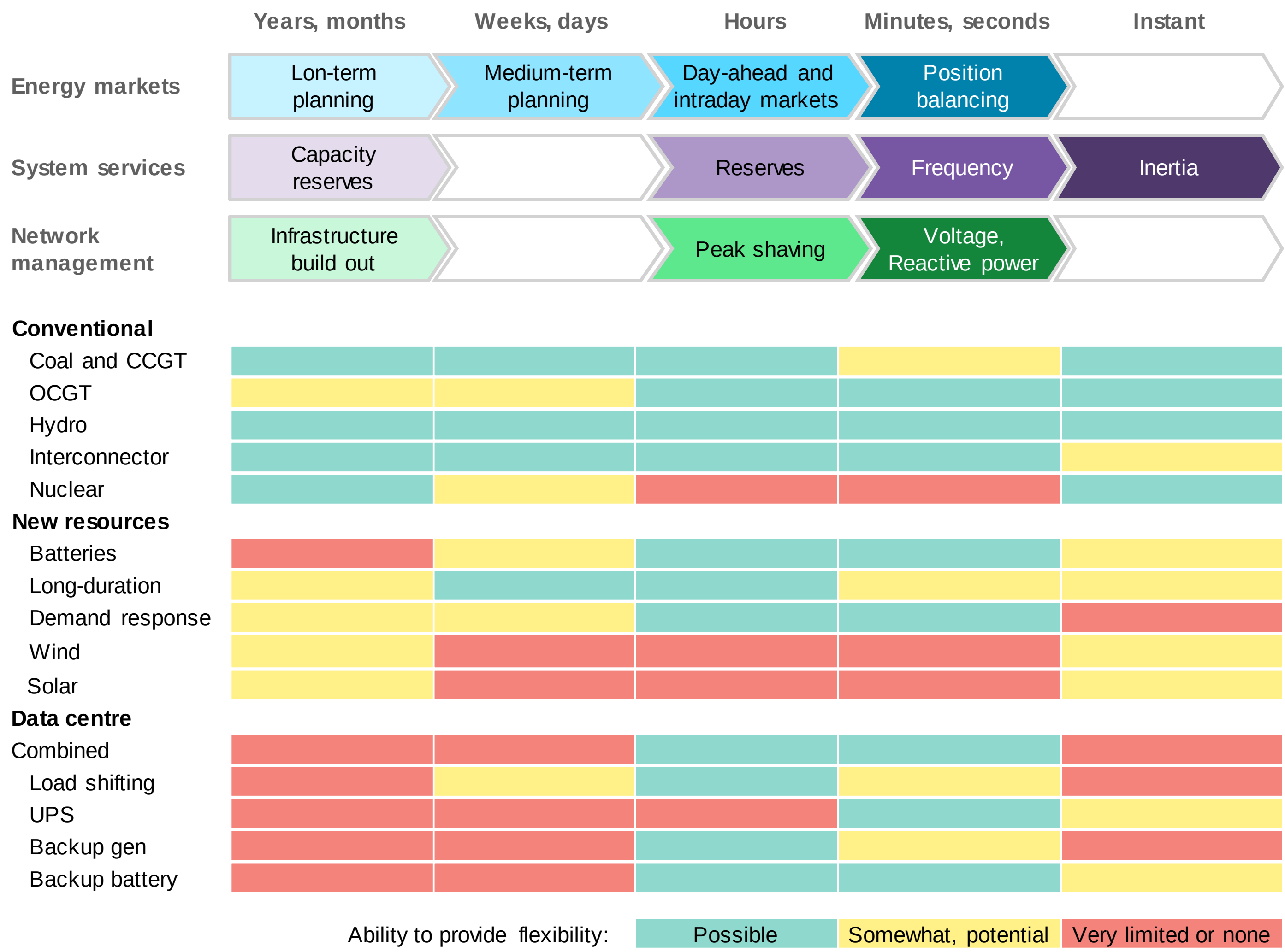
Many power system operators plan to access the flexible aspect of power demand. The European Commission’s Clean Energy Package is clear in its intentions here that power markets should be more accessible to new distributed energy resources such as batteries, on-site generation and demand response.

Data centers can fit into this narrative of a more open, interactive and flexible power system. Data centers could be well suited to providing flexibility to the grid, as they:

- Represent a sizable load that could potentially be shifted in response to grid conditions
- Are a concentrated load in a single location, which can be easier to access than numerous small loads such as homes and vehicles
- Host a range of energy resources on site, such as batteries and generation
- Already have sophisticated monitoring, control, communication and automation systems in place, unlike other businesses or homes

As Figure 24 shows, data centers could provide a range of different flexibility services that could support the power system as it transitions to lower-carbon generation.

Figure 24: Technology suitability to power system flexibility needs



Source: BloombergNEF. Note: AC interconnectors can provide inertia while DC interconnectors cannot.

2.5. Policy measures to address the flexibility challenge

To address the impending flexibility challenge, European system operators and regulators have implemented several changes over several years:

- Created capacity mechanisms to ensure security of supply years in advance, such as in the U.K., France, Italy and others
- Reduced the settlement period in wholesale energy markets to create more granular pricing, as happened in German market reforms in 2011
- Widened the coverage area and created a common platform for system services to allow more competition in the supply of flexibility. For example, the Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation (PICASSO)

project consolidated the market for automatic frequency restoration reserves across 22 European countries.

- Reduced the barriers to entry to existing power and system service markets, an explicit goal of the European Clean Energy Package

While the above reforms help to address system flexibility, more change will be needed. One of the main challenges is to activate distributed energy resources, such as demand response and small-scale generation and storage devices, when needed and for a fair value. Power system and network operators have a number of tools available to access flexible resources. The Council of European Energy Regulators, ENTSO-E and a number of European DNO associations have created a framework of flexibility mechanisms (Table 10).

Table 10: Mechanisms to access flexible resources

Flexibility option	Description	Related BNEF research
A rule-based approach	The network or system operator imposes flexibility requirements on parties connected to the grid through codes and rules	*Renewables Struggle to Integrate on Old Australian Grid* (web | terminal)
Network tariffs	Tariffs charged at meter points are cost-reflective to better align with the charges grid users face with the network costs they cause	*Rooftop Solar Pushes Australian Networks to Tariff Reform* (web | terminal)
Connection agreements	System operators reach arrangements with customers for the provision of flexibility in return for a cheaper connection	*Alternative Connections*: *Good and Bad for Renewables* (web | terminal)
Market-based procurement	Network or system operators procure flexibility from specific resources through a market platform	*Local Flexibility Markets: A Primer* (web | terminal)
Technical solutions using grid assets	A reconfiguration of the grid topology to alter power flows, including reactive power flows, and achieve a more desirable system state	*Smart Grid: From Buzz to Business* (web | terminal)

Source: BloombergNEF, ENTSO-E

There are many examples of each of these mechanisms in action with many lessons to learn on their effectiveness and interaction with new energy technologies such as batteries.

System and network operators are regulated monopolies and are responsible for procuring many of the flexibility needs such as frequency management, congestion management and system reliability. These organizations often need changes to their regulation to allow them to engage with new approaches, which typically rely on software and management solutions as opposed to conventional capital-intensive infrastructure buildout. One of the most discussed changes is to move from a cost-based or revenue cap regulatory regime to an output and performance-based approach. The leading example of performance-based regulation is the U.K.'s RIIO model (Revenue = Incentives + Innovation + Outputs). Read *Smart Grid: From Buzz to Business* (web | terminal) for more detailed on these regulatory changes.

Data centers have not yet been a major target of specific regulation to provide power system flexibility. As we explore further in this report, this may change as data-center capacity increases concurrently with the rise of renewable energy, and other sectors such as transport and buildings electrify too.

Section 3.

Data center flexibility

Section 3. Data-center flexibility

This report has so far established that data centers are a growing force within the European power system, and that this power system has a growing need for flexibility as renewable energy scales up. This section explores whether data centers can be a significant provider of flexibility, evaluates their potential as a flexibility resource.

Data centers are a largely untapped source of flexibility within European power systems. In fact, data centers are themselves sophisticated energy systems that could provide a range of flexibility services. This report considers the following resources within a data center to provide flexibility:

- **Uninterruptible power supply (UPS):** a short-term energy storage device used to ensure seamless data-center operation
- **Load shifting by time:** the potential to defer or schedule computing loads to times that are better suited to power system needs
- **Load shifting by location:** the potential to conduct computational tasks at another data center if this would support the power system
- **Back-up generation (diesel, natural gas and hydrogen):** dispatchable power generation sources co-located with the data center in case of a loss of grid power supply
- **Back-up battery:** additional energy storage capacity co-located with the data center in case of a loss of grid power supply

Other data-center flexibility resources

We do not cover several other potential sources of flexibility due to a lack of available data, the progress of the technologies' implementation today, and the overall potential and likelihood for the future. These include:

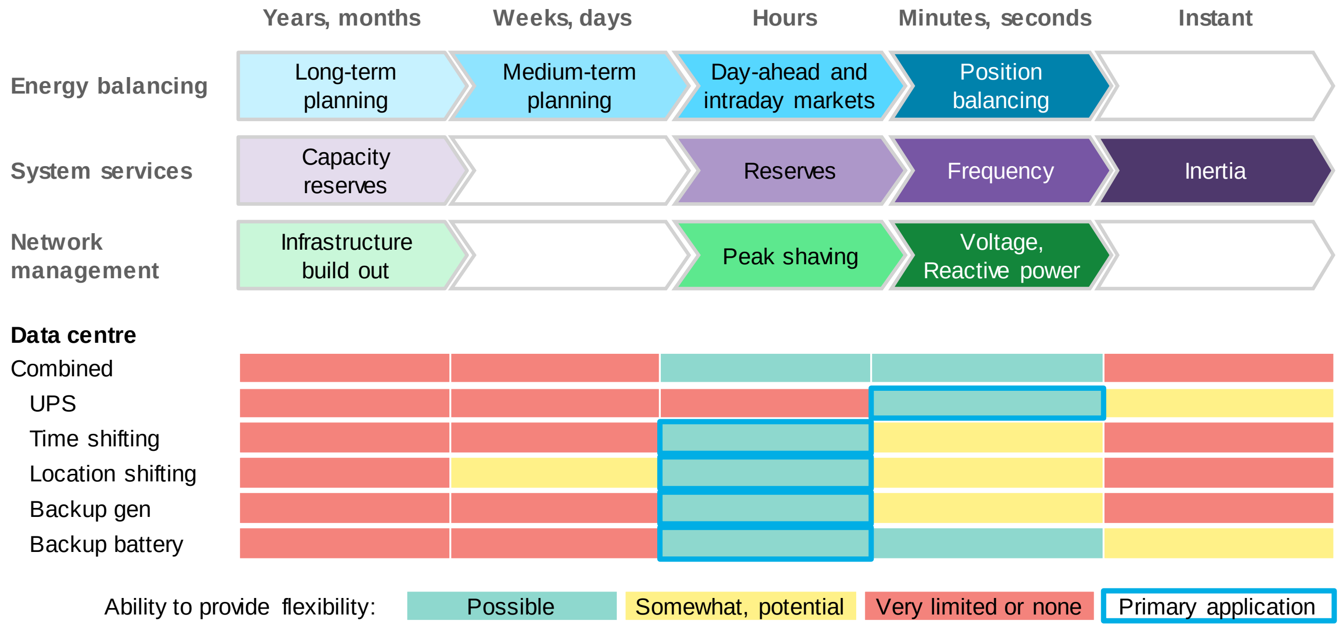
- **Clock speed variation**: the frequency or speed at which calculations are performed, limiting power use in return for slower performance
- **Temperature set point variation**: shifting cooling loads
- **Thermal storage**: on-site storage of cold or heat to offset heating and cooling loads
- **Primary on-site generation:** the use of generators located on the data center site to provide the full power supply

Primary on-site generation or microgrids for data centers receive a lot of discussion and there are several examples already in practice, such as Ebay's use of fuel cells for one of its data centers in the U.S. We did not include primary generation due to uncertainty on the uptake. Feedback indicates that primary on-site generation is more expensive than grid supply, the generation would likely be fossil fuel, the design and build of a data center would be longer and more complex, and the data center depends on a single plant for reliability. Low-carbon generation sources would encourage uptake, but these technologies are still too expensive and are at trial stage today.

3.1. Data center flexible resources

A data center's resources have the technical capabilities to serve a range of flexibility needs (Figure 25). The most important technical capabilities for each resource are its ramp rate, or time taken to reach its max capacity, its duration, or length of time that the flexible response can be maintained, and a realistic notice period that the resource needs to respond to a flexibility signal. In addition, we must also consider how realistic it is that this resource can be diverted away from its primary data-center reliability application, toward supporting the wider power system – or how much of the resource can be harnessed this way without compromising data-center operations.

Figure 25: Flexible capabilities of data-center energy resources



Source: BloombergNEF. Note: Ability to provide a service assessed based on the resource's response times and duration of service

Table 11: UPS flexibility potential assessment

Area	Assessment
Target application(s)	Ancillary svc, eg, freq regulation
Present in data centers?	Yes, very common
Power capacity available	Full, equiv. to data-center capacity
Energy capacity available	Available for only a few minutes
Likely willing-ness to adopt	High, depends on battery type

Source: BloombergNEF

Uninterruptible power supply

An uninterruptible power supply (UPS) is an electrical device that uses batteries to provide instantaneous, seamless transition to emergency back-up power during an outage, for a limited amount of time. Data centers are the major purchasers of these systems, which also improve the power quality during general operations. UPS are typically designed only to provide back-up power for minutes, or enough time for other back-up power comes online, for example a diesel generator. The quick response times and large power capacity, but limited energy capacity, mean that UPS are best suited to provide system services such as frequency response.

UPS are present in all data centers. The battery is typically a valve regulated lead acid battery (VRLA), though lithium-ion batteries are replacing VRLA in recent years due to falling costs and better performance. The UPS and battery are sized for the data-center rack capacity, and a short energy capacity of 5 to 15 minutes.

The full power capacity of the UPS could be made available to provide flexibility to the grid. The data-center operator would limit the amount of UPS battery's energy capacity available for flexibility, as they need a minimum state of charge to ensure its primary function of reliability. This minimum state of charge depends on the data-center operator and the size of the battery. We have seen examples of a minimum state of charge of 50%.

First-mover examples: UPS for flexibility

Several data-center operators are already using their UPS to provide flexibility services. Microsoft is exploring the use of its UPS for frequency reserves in the PJM area of the U.S. In 2019, Basefarm participated in a trial to provide fast frequency reserves to the Norwegian system operator, Statnett[4]. Fellow colocator Digiplex also used its UPS to participate in Statnett's fast frequency product. Most of the UPS flexibility examples involve the UPS providing fast-frequency services, for which the high power, short duration batteries are well suited.

The use of UPS for grid services would not affect the direct performance of the data center, such as data processing speeds, but it may influence the estimated level of reliability. Some data-center operators are concerned about battery degradation due to providing grid services. To mitigate this concern, flexibility providers operate the UPS batteries depending on the technology, the warranty and the flexibility service provided.

Conclusion: *A data center UPS could potentially provide up to its full power capacity for grid frequency regulation, but only up to half of its energy capacity (duration). Most data centers have UPS systems and participation would be unlikely to disrupt operations. Data-center operators are concerned about the degradation of the UPS battery and the potential impact on site resiliency – concerns which can be addressed through trials.*

Time shifting

Table 12: Time-shifting flexibility potential

Area	Assessment
Target application(s)	Energy markets
Present in data centers?	Load is present but shifting is not
Power capacity available	30%-50%
Energy capacity available	Hours – task must be completed by a specific time
Likely willingness to adopt	Low to med, easier for hyperscale operators

Source: BloombergNEF

Data centers serve a range of compute tasks. Some take place in real-time, such as video calls or financial trading, but others do not need to happen straight away, such as data storage back-up or machine-learning training. These are known as 'delay-tolerant' tasks. A data center's proportion of real-time and delay-tolerant tasks will vary based on the data center user, the service and the time of day. There is limited data on the proportion of compute task types, though academic reports indicate 30-50% of compute tasks are delay-tolerant. There is little to no evidence on how these proportions will change due to the rise of internet of things and machine learning. We assume the same proportion for the future. We also assume that the change in compute task is directly proportional to the change in data center power demand. In reality, this energy proportional computing change would vary by data center based on its design and efficiency.

Data-center users already schedule delay-tolerant tasks to manage the data center's computing capacity and to maximize utilization and efficiency. The ability to delay a task depends on whether the user is willing to shift the task, the estimated time taken to complete the task and the time when the user wants the task to be completed. The right signals are then needed to decide when to schedule the task.

Data-center operators and users require lead times of about 24 hours to effectively schedule tasks. Curtailing and rescheduling a task at short notice is possible but we did not identify any examples of this happening for grid services. We assume that tasks can be delayed for up to eight hours. The long lead times and relatively long duration means that time shifting is well suited to energy market operations such as peak shaving or matching renewable generation output, and less suited to system services that require rapid response.

[4] For more details on these UPS frequency reserve trials, see I. Alaperä at al., Fast frequency response from a UPS system of a data center, background, and pilot results, September 2019

First-mover examples: load shifting by time

Google is promoting the use of so-called 'carbon-aware computing'. This involves predicting power emissions intensities for respective data center locations and then scheduling computing tasks to align with those intensities. This aligns with Google's efforts to reach 24/7 renewable energy matching, which means netting off its electricity use against renewable generation at an hourly level as opposed to the current annual standard. Fellow hyperscale operator Microsoft signaled similar aspirations. The colocation operator Iron Mountain has also made steps in this respect and in April 2021, started to offer its customers the ability to track renewable energy use by the hour.

Time-shifting load is difficult. Today we see the early movers, Google and Microsoft, but the spread throughout the wider industry and to data-center users will take several years. By 2030, we believe that half of hyperscale operators would use load shifting with colocation providers lagging with less than 10% of those data centers shifting load.

Data-center operators and users need to receive the right signals to encourage shifting and to design software and applications with this in mind. There is a difference between the different data center types and whether they are exposed to the signal, such as time-varying power prices, or can forecast and schedule the compute tasks. For example, a colocation provider cannot see or control the compute tasks, while hyperscale operators can manage their internal applications.

Conclusion: *In principle, 30-50% of data center compute tasks could be time-shifted. Forward planning is needed, meaning the key application is in energy markets rather than system services. Unlike UPS or back-up generators, time shifting directly impacts users, delaying the time to complete a compute task by potentially several hours. Data-center users need to right signals to incentivize load shifting.*

Location shifting

Table 13: Location-shifting flexibility potential

Area	Assessment
Target application(s)	Energy markets
Present in data centers?	Load is present but limited shifting
Power capacity available	30%-50%
Energy capacity available	Hours – based on compute capacity in data centers
Likely willing-ness to adopt	Operator must run multiple data center sites

Source: BloombergNEF

The ability to shift the location of a task is not a new idea. Data-center operators with multiple sites may move tasks to optimize the efficiency and utilization of its data center fleet, or to take advantage of lower energy prices in specific locations. The ability to shift load depends on whether the compute capacity is available and the destination site has the suitable hardware and software for the data transfer. Transferring the computation from one site to another requires energy, which the data-center operator should take into account when assessing the cost and carbon benefits of shifting tasks.

The amount of load available to be shifted is difficult to quantify and will depend on the specific data-center user and operator. Though there is little data to go on, so we assume the same proportion of load that can be shifted by time (50%) could also be shifted by location in 2030. Similarly, we believe that the load will be moved back to the originating data center within eight hours of the initial transfer. Like time shifting, the data-center operator would want to have foresight on any location-shifting action, such as how much load to shift, to where, and in response to what signals. This limits the application primarily to energy market trading, rather than system services.

Shifting the load would likely mean moving the task to a location further away from the user and therefore increase the latency for the task. It depends on the task, but research by Microsoft showed that location shifting within Europe increased the user's experienced latency in a video call by 10%, which Microsoft felt was negligible. Transferring the computation across the network takes time to complete and can add to the latency.

Uptake of location shifting in 2030 will be higher for hyperscale data centers, at 25%, than for colocation operators, at 5%. Hyperscale operators have greater freedom to move loads than colocation providers, through the direct ownership of server capacity and the ability to allocate compute tasks.

When implementing location shifting, one must consider whether the data can be moved outside of a particular jurisdiction or country, for example due to data privacy governance or national security. This data limitation may not be large but data-center operators should keep this limit in mind.

Conclusion: *Location shifting is possible in principle, and perhaps as much as half of tasks could be shifted to other locations. We see some examples today but overall, the uptake will be limited as the data-center operator must have access to several sites and have the freedom to move the computation. The practicalities have not been explored in detail and are likely to require more investigation than other resources discussed here.*

Back-up generation

Table 14: Back-up generation flexibility potential

Area	Assessment
Target application(s)	Energy markets
Present in data centers?	Yes, very common, mostly diesel
Power capacity available	Full, equiv. to data-center capacity
Energy capacity available	2-8 hours, depends on stored fuel
Likely willing-ness to adopt	More likely for low-carbon fuel. Concern for reliability

Source: BloombergNEF

Data centers have on-site generation to provide power to the building in the event of a loss of grid supply. The back-up generation is generally diesel due to its quick ramp up times (a matter of minutes), and low cost when used infrequently. Operators are looking at alternatives to diesel due to environmental concerns and regulation. Data-center operators size the generators to cover the maximum load of the entire data center site and store enough fuel on site for times ranging from a few hours to several days. The amount of reserve fuel depends on the desired level of reliability and on the potential duration of outages in the local area. The generator lies idle much of the time and, ideally for the data-center operator, is never used.

We assume that the full back-up power capacity could be used for flexibility, though in reality the data-center operator may be unwilling to use all its generators and would withhold some capacity as a reliability precaution. The available energy or duration depends on how much reserve fuel the data-center operator wants to have left in case of a loss of grid supply. The ability to restock fuel reserves would also be a concern. We assume that the data-center operator would have eight hours of reserve fuel on site and is willing to use two hours for flexibility purposes.

Back-up generators are best suited to provide hourly flexibility services that require response and duration times in terms of minutes or longer. This means it is best applied to energy market applications, such as reducing peak demands on the system and on the local network. Data-center operators could also use back-up generators to avoid peak energy prices.

The willingness to use back-up generation faces many of the same reliability concerns as using the UPS – that using the back-up supply would hurt the site's reliability, degrade the equipment and may lead to a loss of service to their users. Unlike UPS, there is an additional environmental concern about using fossil-fuel generation for flexibility services, in particular diesel generation which has a high emissions intensity and causes local air pollution. Since diesel is so polluting, it would not be appropriate to conduct energy market operations frequently, meaning these resources should only be used during extreme periods of capacity shortage on the power system.

There are already limits on the use of diesel generation for system services in many countries. It is likely that very few diesel back-up generators (2%) will be used for flexibility services in 2030.

Natural gas and hydrogen generators would be less limited and up to 30% of data-center operators may be willing to participate those resources in energy markets and system services.

Some data centers use natural gas as back-up generation and others are looking to move away from diesel. Microsoft plans to be diesel free by 2030. While natural gas is a cleaner alternative to diesel, zero-carbon alternatives such as biogas, biodiesel and green hydrogen will ultimately be needed if this application is to take off. While there are some examples of these alternatives today, such Microsoft's use of hydrogen fuel cells, they are not yet commercial. The cost and reliable supply of these fuels could also be a challenge.

Data centers already regularly run their back-up generation for maintenance purposes, to ensure that it is working and reliable when needed. In some cases, the organization could run their back-up at the same time as a grid reliability event. This means that the generator is not run any more than it typically would have been but now generates additional income and supports the grid.

Conclusion: *Back-up generators could provide much of their capacity to the grid for energy market applications and run for hours. This could happen either by supplying the data center (thus reducing power draw from the grid), or by actually injecting power to the grid if the data center is not running at high power at the time. But generators must move away from polluting diesel to play anything more than an emergency back-up role.*

Back-up battery

Another alternative to back-up generation is a large-scale battery located with the data center, to supply power in the event of a grid interruption. However, the required size of the battery to provide adequate back-up is prohibitively expensive compared to conventional back-up generation, as well as being untested. We identified only one dedicated back-up battery, Google's 2.7MW/5.4MWh battery at one of its data centers in Belgium. Considering this low base, we assume that very few data centers, less than 3%, have back-up batteries by 2030.

Table 15: Back-up battery flexibility potential

Area	Assessment
Target application(s)	Energy markets, and system services
Present in data centers?	No, still in pilot stage
Power capacity available	Full, equiv. to data-center capacity
Energy capacity available	Up to 50%
Likely willing-ness to adopt	Additional revenue is vital to business case

Source: BloombergNEF

An on-site battery can provide a range of flexibility services to the grid. Similar to UPS and back-up generation, the data center would only make a proportion of the battery available for flexibility, reserving the remainder for site reliability purposes. We assume that 50% of the battery's energy capacity is available for flexibility services.

Considering the high cost of installing a battery, it is likely that a data entre operator would be open to using the resource to optimize its energy consumption and to provide system services. The access and value of system services could be a key enabler to improving the economics for data centers to install larger batteries. Google chose Belgium for its first back-up battery because of the access and value of the country's system services. Further cost reductions in battery will costs will improve the economics of back-up batteries.

Conclusion: *We know of only one data center back-up battery trial today. Industry-wide adoption will take many years and further battery cost reductions will help. Where a back-up battery is installed, it is highly likely that the resource will be used for flexibility services.*

Combining flexible resources

The above flexible resources are mostly in early stages individually, so we do not explore the potential of combining them to provide flexibility. The proposition is intriguing however, and could serve several uses, including:

- For greater flexible response, a data-center operator can time-shift load while at the same time exporting its back-up generation to the grid, thus changing its position from a power importer to a power exporter.
- For reliability purposes, a data center can install a back-up battery, which has a shorter duration than traditional diesel generator, but could use that extra time to shift compute to another location and ensure continuity of service.

It will be several years before practices like these are widespread. There are still many lessons to learn for the individual flexible resources and combining will bring many more new lessons.

Flexible demand versus grid injection

Not all of these resources provide the same function. Some resources (eg, load shifting) simply alter the site's demand, while others can either offset on-site demand or inject energy to the grid (eg, batteries or generation). The overall impact on the system is the same whether flexible demand and injected into the grid but how it is measured is different. Flexible demand is measured against an expected baseline demand and could vary during a response due to changing demand. Grid injection is more straightforward as it measures the flexible resource directly.

Some data-center operators are wary of injecting directly into the grid as this would entail greater administration for export licenses. Flexibility and virtual power plant operators can assist with this process.

3.2. Total available flexibility from data centers

We have built up a view on three key figures to estimate how much total flexibility these data-center resources could offer in 2030:

1. The likely installed base of these resources (ie, how many data centers have them installed)
2. How much of that resource could technically be offered as flexibility to the power system without majorly affecting data center operations
3. What proportion of data-center operators might be willing to participate in such a program

Points 2 and 3 can be thought of as 'haircuts' on the installed base: first to determine how much capacity *potential* there is, and then to determine how much might plausibly be *available* given that data-center operators' willingness to participate may be far from 100%.

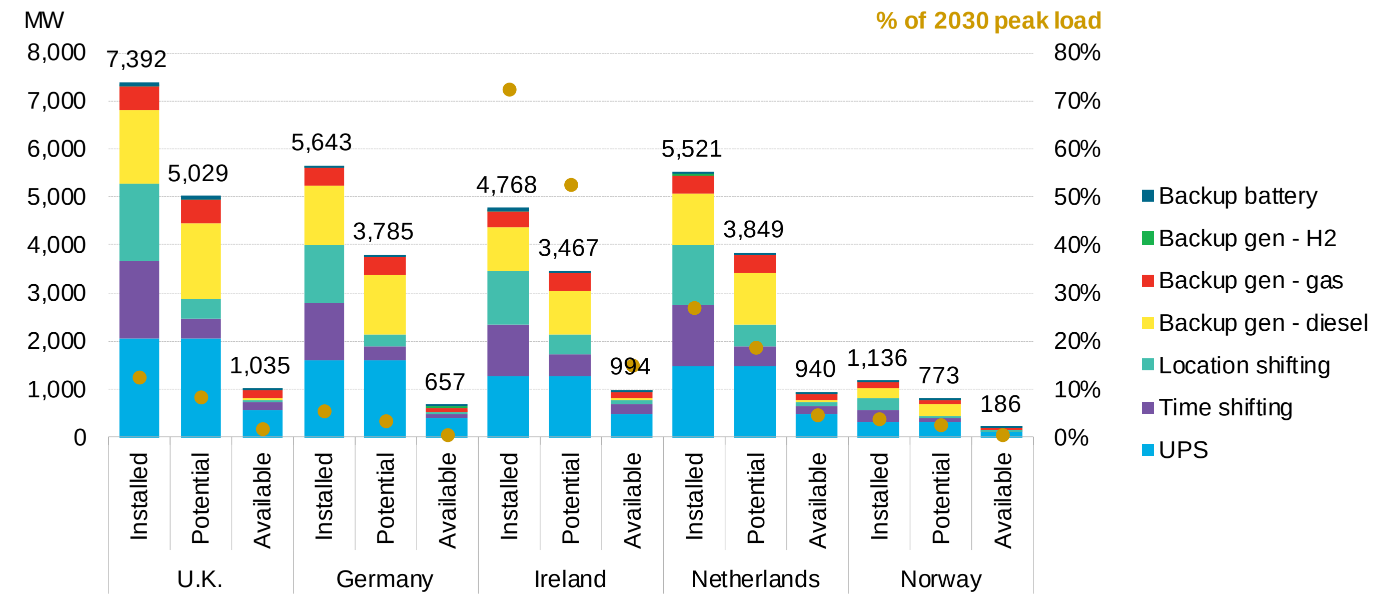
To give a brief idea, based on our research and conversations with a variety of stakeholders, we find that:

- Most European data centers have UPS and fossil-based back-up generators installed, typically sized to their rack capacity. Very few have back-up batteries or clean (hydrogen-based) back-up; these are in pilot stages today. Time/location-based load shifting are theoretically possible today and sized based on the live IT power.
- The power and energy capacity that could be offered up varies by individual resource type (this was discussed in the section above).
- Willingness to participate is likely to be low across the board, making this third haircut the most important of all (discussion below).

Figure 26 below shows our results in summary, for the five countries covered. Looking first at Germany in 2030 as an example, a few key findings are apparent:

- The combined *installed* flexible capacity for Germany in 2030 is very high at 5,640MW. Note that this is significantly higher than our estimated live IT power for data centers in Germany in that year, at 1,200MW. This is because the different resources in the data center sum up to more than the power demand of the data center itself. In principle, the resources could each be applied to provide flexibility independently (though this might be hard in practice, eg, because of limited grid connection capacity or other limitations).
- The *potential* capacity is much lower, at 3,800MW. This reduction reflects the technical limitations of the resources, accounting for capacity that must be reserved purely for the data center. Most importantly, we assume that time- and location-based load shifting are suited to deliver day-ahead flexibility, which aligns with the data-center users' needs.
- The *available* capacity in Germany in 2030 drops to 660MW once we account for how much data-center operators might actually be willing to participate. This is still a substantial amount and is more than the 570MW required for Germany's frequency containment reserve in 2020.
- The large fall from potential to available flexible capacity is due to the small capacity of hyperscale data centers in the country and the large number of existing sites. Colocation and existing data centers are less likely to participate in flexibility programs.

Figure 26: Data center 2030 flexible capacities by country



Source: BloombergNEF, ENTSO.E. Note: Based on medium scenario for data-center installations (Section 1). Ability to provide a service assessed based on the resource's response times and duration of service. Installed *refers to the total amount of the flexible resource present in data centers.* Potential *is the technically able capacity for each resource based on practical data center limits.* Available *refers to the capacity that data-center operators are willing to participate in flexibility.*

Here is a summary of the findings for the other countries:

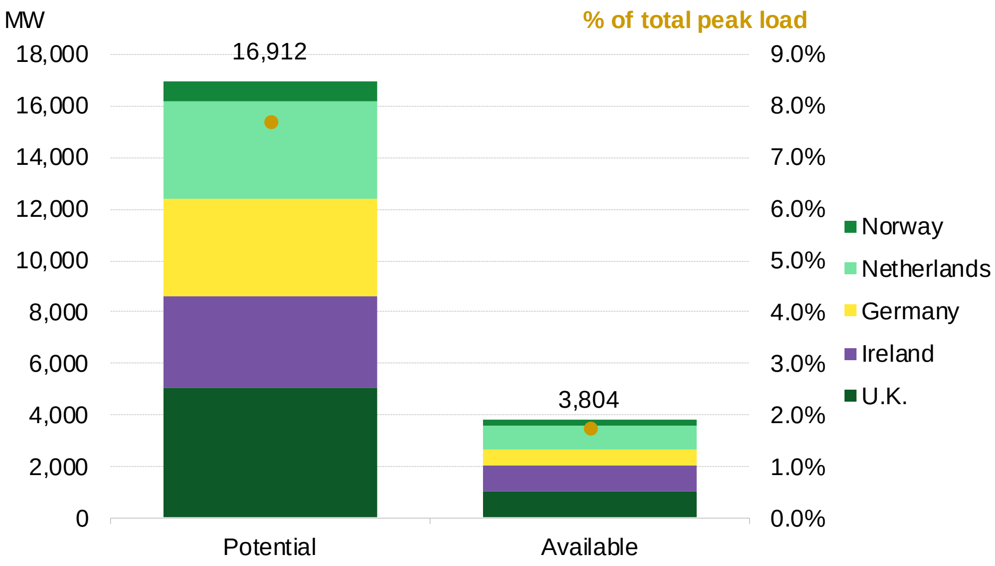
- The U.K. has the highest installed capacity of the five focus countries but like Germany, this capacity plummets due to the high proportion of existing, colocation data centers. Notwithstanding, 1GW is still the second highest available flexible capacity in 2030, after

Ireland, and is comparable to the region's required system services today – frequency containment reserve at 650MW and frequency restoration reserve also at 650MW.

- For Ireland, the available flexible capacity is 1GW in 2030 or almost 15% of the all-island peak demand. This is a sizable capacity and twice the estimated 470MW of battery storage in 2030. Ireland has the highest proportion of flexible capacity to peak demand of the five countries, which is unsurprising considering Ireland's high data-center capacity and large proportion of hyperscale operators present.
- The Netherlands, like Ireland, has a large data-center capacity relative to its power system. This means that data-center flexibility could play a significant role. The 3,800MW of potential flexible capacity equates to almost a fifth of the country's 2030 peak load of 20GW. The available flexible capacity of 940MW could play a big role in Dutch flexibility markets, being far greater than the 110MW needed for frequency containment reserve today. It is also greater than the estimated 730MW of vehicle-to-grid flexibility in 2030.
- Data-center capacity is still low in Norway relative to the other focus countries. This means the available flexible capacity of 190MW is less than 1% of Norway's peak power demand. The country is already host to energy-intensive industries such aluminum smelters, which drives up demand. The potential flexible capacity of 780MW is still a significant amount of flexibility and is comparable to the 925MW of battery storage expected in 2030.

Combining the data center flexible resources for all countries provides a total *potential* flexibility capacity of 16.9GW and an *available* flexible capacity of 3.8GW (Figure 27). The potential capacity relative to the total peak load of the five focus countries is significant, at around 8%. After taking into account data-center operator willingness, the ratio to peak load falls to 1.7%. While data centers are a large load on a countries' power system, and have the potential to offer sizable flexibility, their willingness to participate will be the key determinant of their impact.

Figure 27: Data center flexible capacity and as a percentage of the focus countries' total peak load in 2030



Source: BloombergNEF

3.3. Available flexibility from specific resources

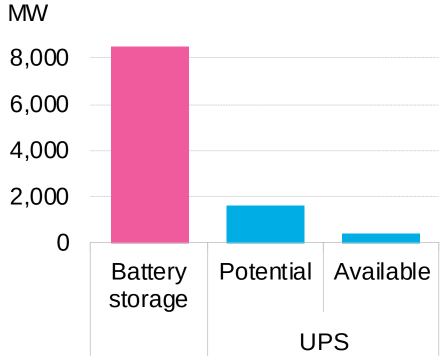
Data-center flexible resources will be comparable in size, performance and impact to other similar resources. UPS systems are fast-acting and can provide similar services as other batteries connected to the grid. Though load shifting is not common amongst data centers, the idea is gaining traction in other sectors, such as electric vehicle charging – and the volumes of energy are comparable. Data center back-up generation is largely fossil-fuel based, but it could switch to low-carbon sources then it would represent a sizable amount of flexible resource.

Uninterruptible power systems

A UPS has many of the same performance characteristics as another grid-connected battery, such as fast ramp rates. While a UPS' short duration limits its potential in energy markets, it is well suited to serving grid-frequency services. Battery storage is and will be used for a range of applications, and our previous modelling has indicated that 8,500MW of batteries could be deployed in Germany by 2030. The *potential* 1,600MW of UPS we calculate in this report could offset some of that battery build, reducing the needed investment in storage plants. In addition, the increased supply of UPS capacity for frequency services would increase competition and reduce costs for consumers.

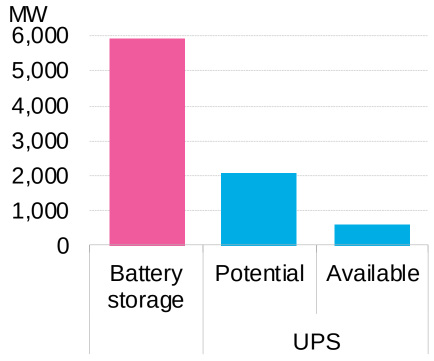
Ireland is a different story to the other focus countries. Due to the relative high amount of data centers, the potential UPS capacity (1,300MW) and available flexible capacity (480MW) are close to the expected 470MW of batteries in 2030. Irish data-center UPS therefore represent a large flexible resource on an isolated power system that will need a lot of flexibility in the future.

Figure 28: Germany battery storage capacity versus data-center UPS capacity in 2030



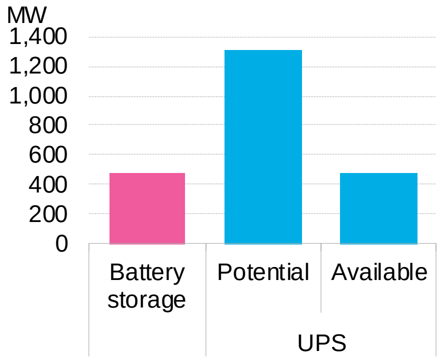
Source: BloombergNEF

Figure 29: U.K. battery storage capacity versus data-center UPS capacity in 2030



Source: BloombergNEF

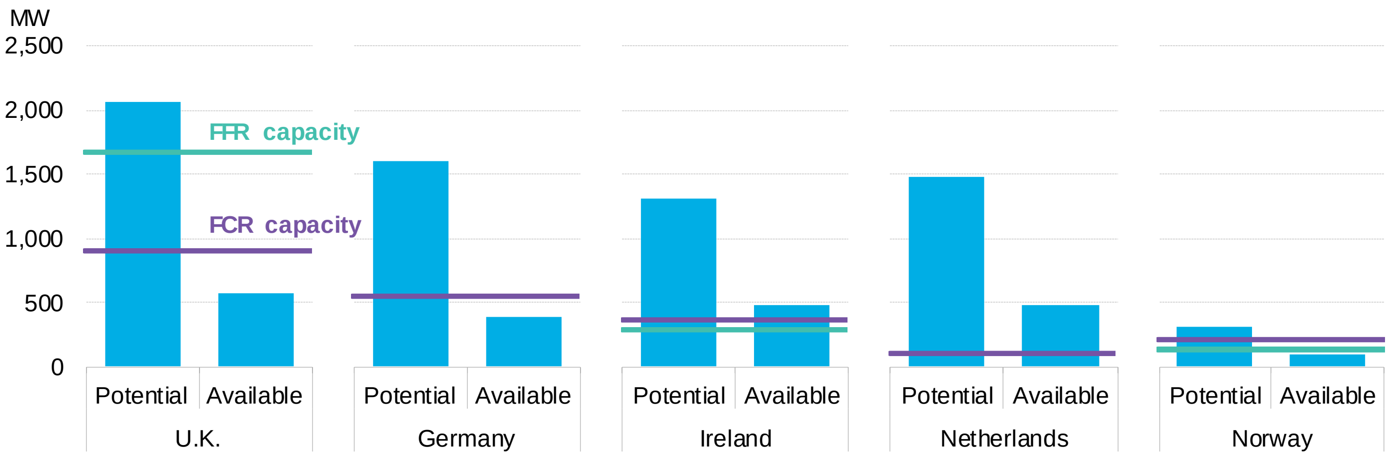
Figure 30: Ireland battery storage capacity versus data-center UPS capacity in 2030



Source: BloombergNEF

UPS capacity could be more than enough to meet grid frequency reserve needs. In Europe, there are two grid frequency services which require response times in the matter of seconds and last for no more than 30 seconds: fast frequency reserves (FFR) and frequency containment reserves (FCR). In almost all the countries, the *potential* UPS flexible capacity in 2030 is enough to meet the capacity needed for these services in 2020. In Germany, Netherlands and the U.K., there would still be enough UPS flexibility if the needed FCR capacity doubled. Ireland is interesting where the available data-center UPS capacity could serve the FCR and FFR capacities. Norway's data-center capacity relative to its power system size is small compared to the other focus countries, though its potential UPS capacity in 2030 compares well against FFR and FCR needs today.

Figure 31: UPS flexible capacity in 2030 and the 2020 average contracted fast frequency response (FFR) and frequency containment reserve (FCR) capacity



Source: BloombergNEF. Note: Fast frequency response products are not available in Germany and Netherlands.

These frequency services are typically called up for large deviations in the system's frequency, for example when a large power plant unexpectedly goes offline. This means that they are not frequently called upon and are more in place as a safety precaution. This infrequent use of the battery should mitigate data-center operators' concerns about battery degradation.

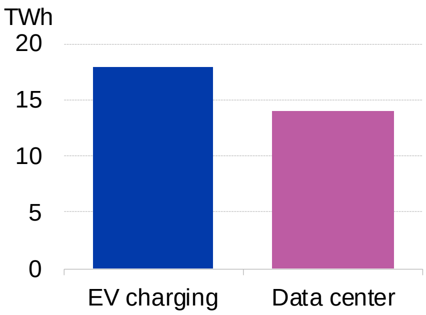
Time- and location-shifting

Load shifting will be needed to match demand to variable renewable electricity supply. Several sectors are exploring load shifting today and many promote electric-vehicle (EV) charging to be an important flexible load in years to come. Here we show a comparison of EV charging and data-center load shifting potentials in the U.K. in 2030.

U.K. EV-charging and data-center electricity use is comparable in 2030 according to our projections (Figure 32), but we see a difference in their load-shifting potential (Figure 33). We estimate that 2,400GWh, or 17% of U.K. data-center load, has the *potential* to be flexible by 2030. However, the *available* load-shifting from data centers is only 600GWh, or 4% of the total data-center load, due to the large segment of colocation operators in the country, which have limited ability to shift load, particularly by location. This is significantly less than the expected 4,300GWh EV-charging flexibility, or 24% of the total annual EV-charging consumption. If concrete steps are taken to unlock data-center flexibility, or EV charging flexibility falls short of expectations, this balance could shift.

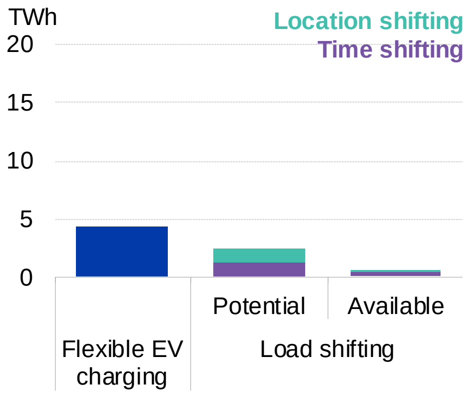
Data centers have an advantage as large concentrated loads, as opposed to fragmented and dispersed EV chargers. This greater centralization means that the load is easier to monitor and control, requiring response from hundreds of data centers as opposed to thousands or millions of electric vehicles. This would be more beneficial for system services, as the majority of EV charging flexibility will come from responding to pre-set time-of-use tariffs.

Figure 32: U.K. EV charging and data-center annual electricity use in 2030



Source: BloombergNEF.

Figure 33: U.K. annual flexible loads in 2030



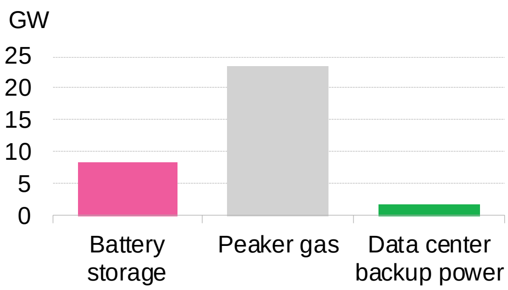
Source: BloombergNEF. Note Assume 24% of EV charging demand is flexible.

Back-up generation

Fossil-fuel based data center back-up generation is not suited to a net-zero emissions future and should be run as little as possible. Regardless, the back-up generation capacity can be substantial and if it were to be low- or zero-carbon (eg, using hydrogen or bioenergy), then it could offer material flexibility. The short duration of data center back-up means that it is better suited to providing power during peak times. This means back-up power is comparable to battery storage or peaker-gas generation, but not combined-cycle gas turbines which operate for days or weeks on end.

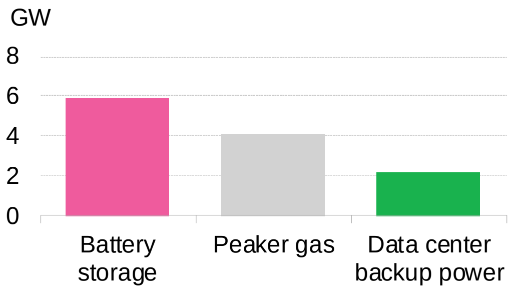
The materiality of back-up generation in a country's power system depends on the makeup of the grid and relative size of the data-center fleet. Regardless of the proportion, the back-up could offset the build of new gas-peaker plants or battery storage, along with the cost and embodied carbon. Germany's large power system, with a 2030 peak load of 100GW, means that the 1.6GW of *available* data center back-up is a fraction of the 24GW of peaker gas. But in the U.K., which has a smaller power system and a 2030 peak load of 58GW, the 2.1GW of data-center back-up capacity is comparable in scale to the 6GW of battery storage and 4GW of peaker plant.

Figure 34: German data center back-up power, battery storage and peaker gas capacity in 2030



Source: BloombergNEF

Figure 35: U.K. data center back-up power, battery storage and peaker gas capacity in 2030



Source: BloombergNEF

3.4. Flexibility potential by data center type

In our analysis, hyperscale data centers represent a larger amount of flexible capacity compared to colocation operators, as they are more advanced in adopting new energy resources and flexibility, such as Google's Belgium battery or Microsoft's back-up fuel cell. With that said, the barriers to colocation adoption are not technical and can be overcome through greater experience.

Table 16 shows the assumptions we used when estimating data-center operators' willingness to participate in providing flexibility. These were based on extensive interviews, and broadly reflect greater willingness among hyperscale operators and new-build facilities.

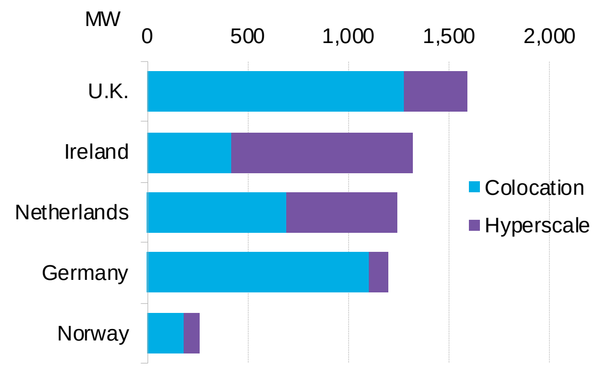
Table 16: Assumptions on data-center operators' willingness to use resource for flexibility

	Colocation		Hyperscale	
	New build	Existing	New build	Existing
UPS	30%	20%	50%	40%
Time shifting	30%	30%	50%	50%
Location shifting	5%	5%	25%	25%
Back-up gen: diesel	2%	2%	2%	2%
Back-up gen: gas	30%	20%	50%	40%
Back-up gen: hydrogen	30%	20%	50%	40%
Back-up battery	100%	100%	100%	100%

Source: BloombergNEF

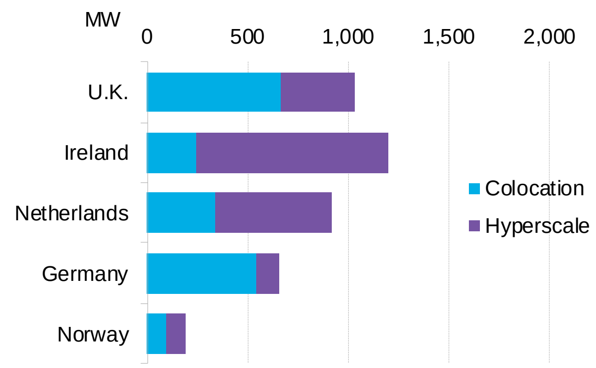
In sum, our research indicates that hyperscale operators' earlier adoption will translate into more flexible capacity than colocation operators. In 2030, the Netherlands has 700MW of live colocation IT power and 550MW of live hyperscale IT power, a 56-to-44 split (Figure 36). In contrast, the respective available flexible capacity is 340MW and 580MW, a 37-to-63 split (Figure 37).

Figure 36: Data-center live IT power, 2030



Source: BloombergNEF

Figure 37: Data center available flexible capacity, 2030



Source: BloombergNEF

There is some historical precedent to indicate that hyperscalers might be faster to adopt, as they were also the first to sign power purchase agreements (PPA) with renewable power plants. Google signed its first PPA in 2010 and was soon followed by its peers. Equinix was the first colocation operator to sign a PPA, in 2015 (Figure 38). Today, we already see some colocation operators engaging with new technologies and flexibility, so it is unlikely that colocation companies will not lag the hyperscale operators in this new aspect, as much as they did with PPAs.

Figure 38: Year data-center operator signed first power purchase agreement

Source: BloombergNEF PPA Tacker

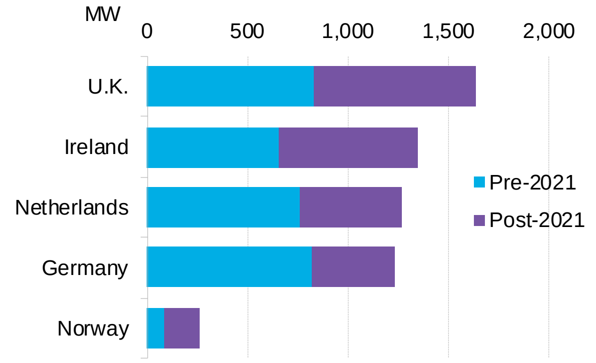
The colocation operators lag hyperscale providers in adopting new technologies due to the differences in the business models. Hyperscale providers have greater control across the entire ‘data vertical’ than colocation companies. This means that hyperscale companies often build, own and operate the entire data center, with control over the hardware and visibility of the data and processes. Colocation companies do not have this control over the servers installed at the site or any control of the data and processes within those servers.

There is also the simple point of the size of these companies. Hyperscale providers are some of the wealthiest companies in the world and have the resources to explore new technologies and approaches, such as batteries and fuel cells. As of writing, one of the largest colocation providers, Equinix, has a market cap of $70 billion. Alphabet, Google’s parent company, has a market cap of $1.8 trillion and Microsoft a value of $2.3 trillion.

3.5. Flexibility from existing versus new build data centers

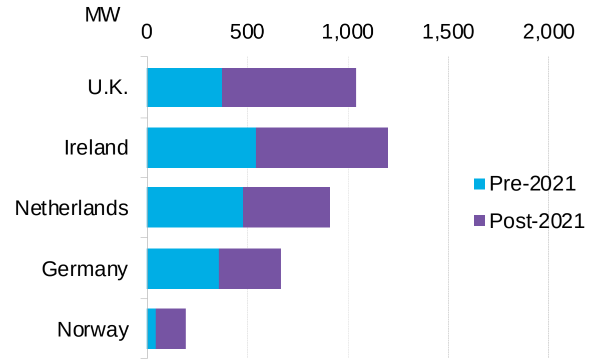
New-build data centers or new live server capacity are more likely to be flexible than existing data-center capacity. Data centers built in the future will have a greater proportion of flexibility capacity (Figure 39, Figure 40). The new installations will more likely have the controls and communications required to operate for flexibility services. Similarly, new back-up power technologies, such as large batteries or low-carbon generation, will be installed in new build. There may be some instances of retrofitting existing sites with these new technologies, but this will be relatively expensive. Load shifting depends on a change to operations and not new technologies so its use in existing build is as likely as new build.

Figure 39: Existing and new build live IT power in 2030



Source: BloombergNEF

Figure 40: Existing and new build available flexible capacity in 2030



Source: BloombergNEF

Section 4.

Unlocking flexibility in data centers

Section 4. Unlocking flexibility in data centers

The analysis in the previous section shows that the technical potential for data centers to provide flexibility is high, but the actual available capacity is likely to be low given data-center operators' low perceived readiness to participate.

Data-center operators have not engaged meaningfully with the issue of power system flexibility up till now, as their primary focus is rightly on ensuring reliable data storage and processing. However, as sophisticated energy resources with large loads and on-site resources, such as batteries and generation, data centers are a largely untapped resource of flexibility for power systems.

Data-center operators could capture several benefits by providing flexibility services to the grid:

- **Financial:** reduce or offset energy costs by optimizing energy use against energy prices and network charges, or providing flexibility services to the system operator
- **Environmental:** reduce carbon emissions from own operations by aligning energy use with renewable generation, or displace the use of fossil fuel generation for system and network flexibility needs
- **Connections**: grid connections with agreed flexibility may enjoy cheaper and quicker connection times due to less infrastructure reinforcement needed
- **Pre-empt regulation:** data centers are large loads and further build-out could put further strain on the power system, leading to regulatory intervention. Acting pre-emptively and reducing this power system strain through flexibility can offset this need for intervention.

Data centers are more efficient than individual computers or private servers, and overall will reduce energy consumption for computation tasks. They are a key enabler for the 21st century digital economy and are already doing more to run their operations from renewable energy. The benefits of flexibility represent the next frontier for how operators can contribute to the low-carbon transition.

4.1. Carbon benefits of data-center flexibility

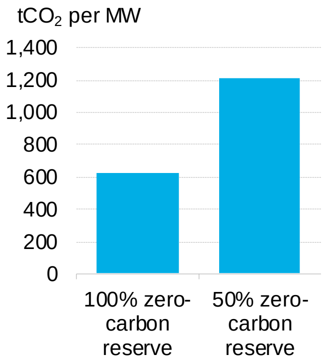
Operating a data center flexibly can reduce carbon emissions from the data center itself, as well as helping reduce emissions for the overall power system. Each flexible resource can reduce emissions in different ways. The reductions can come from:

- **Carbon arbitrage by time:** moving demand from times of high grid emissions intensity to times of low emissions intensity. With some foresight, the data-center operator can reduce its carbon emissions by moving load from one time to another (mainly to times of high renewable generation). Moving load in this way would also generate cost savings as times of high renewable generation generally align with times of lower power prices.
- **Carbon arbitrage by location:** moving demand from a data center in a country or region experiencing high grid emissions intensity to a place of low emissions intensity at the time of demand. This concept can also be applied to moving demand to places where the increased demand will help to reduce renewable energy curtailment, or what could be termed 'curtailment chasing'. The carbon benefit is the marginal emissions: how much carbon is saved in the original data center location and how much is added in the destination data center location.

- **Displacing fossil generation:** the data center can use a flexible resource to displace a service provided by a thermal generator. For example, a data center's UPS, back-up battery, flexible load or back-up generator (if clean) could be used for system services such as frequency reserves, displacing fossil-based generators that would otherwise be on standby to provide the service.

Estimating the environmental benefit of location shifting can be challenging. The carbon savings depend on the marginal emissions intensity at the originating and destination data centers. This means working out which generation source is reduced in the originating area and which is raised in the destination region. There is no standardized method of calculating the carbon saved and no data centers are doing this at scale. A more straightforward assessment would be whether the load shifting removes the need to curtail renewable generation in the destination region.

Figure 41: Avoided carbon emissions in 2030 Irish system due to zero-carbon flexibility for system services



Source: Energy Storage Ireland, BloombergNEF

The above mechanisms are focused on the data center's own emissions (including scope 2), but there is also a wider system benefit of providing clean flexibility. This is not straightforward to model, but a study[5] of the Irish power system found that if zero-carbon sources of flexibility, such as batteries or demand response, were to provide half of the required reserves (350MW) in the all-island Irish power system, this could avoid 400,000 metric tons of CO_2 a year by 2030. In this scenario, 1MW of zero-carbon reserve would save over 1.2 tons of CO_2 a year in 2030. There is a point of diminishing returns in terms of the carbon benefit: if 100% of reserves came from batteries and demand response then the savings per MW would halve to about 0.6 tons (Figure 41).

The report goes further and claims that if all reserves and other system services and constraints were solved by zero-carbon sources, the amount of curtailed renewable generation in 2030 would be halved from 8.1% to 4%.

While the above study was theoretical, the potential for zero-carbon sources to provide reserves to the grid is real. The system operator in Great Britain, National Grid ESO, ran a trial in 2020 that saw batteries provide reserve services. Over a three-week period, four large-scale batteries, ranging from 41MW to 49MW, provided reserves to the system operator, a service which is typically supplied by thermal power plants. The trial succeeded in its aims and estimated that it saved of 700,000 pounds on system service costs. The savings were from the payments that would have otherwise gone to other conventional providers of reserve.

4.2. Key issues to address in accessing data-center flexibility

Data centers will host significant amounts of flexible resource by 2030, but there will be significant challenges in unlocking it. This is illustrated by the big gaps between *installed, potential* and *available* capacity results in Section 3 above.

Accessing these resources, while challenging, presents significant opportunities. Data-center operators can play an active role in enabling the power sector's low-carbon transition, while power system operators can gain access to more flexible resources, supporting a more efficient and resilient low-carbon power system.

There are also significant risks for data-center operators, if data-center load growth rises in an uncontrolled fashion, causing grid reliability concerns, and countries impose stringent limits on their growth.

[5] Energy Storage Ireland, Store, Respond and Save, December 2019

Service-level agreements may prevent operators from participating in flexibility

A data-center operator's primary mission is to provide reliable data storage and processing to its customers. Many data-center operators believe that any flexible action would interfere with that primary goal, either through poorer computation performance or a less reliable service. Data-center operators are often unwilling to explore the feasibility of flexibility because of these concerns.

Data-center operators and their customers have clear service-level agreements (SLAs), which lay out the performance expectations such as latency, processing speed, uptime and storage capacity, etc. Many operators worry that any flexible action would contravene the performance standards defined in the SLA.

However, SLAs are contracts and the terms of a contract can be changed. For example, academia has proposed the idea of a 'GreenSLA', which includes environmental standards in the performance clauses. One flexibility operator we spoke to, who works with data centers, contacted the data-center users to change the SLA to allow for the flexibility. The customers agreed to the change and the data center now provides system services. Several interviewees said that when re-negotiating the SLA, it is important that the flexibility benefits are communicated and allocated appropriately, such as shared revenue from the flexible service. In addition to the customer contracts, a data-center operator also has agreements with subcontractors and other stakeholders such as insurance providers.

Our take: *Service-level agreements are a key sticking point preventing data-center operators from considering adopting greater flexibility. Re-examining their design and the effects of flexible operation could allow more operators to participate in power market flexibility.*

Some operators lack understanding of power markets and system services, and financial incentives may not always be sufficient

While data centers are sophisticated energy consumers, they often have limited understanding of power system flexibility and system services. Again, this is not a data center's core competence, and these flexibility markets can be complex to understand. In addition, system service payments are usually market-based, meaning they can fluctuate over time. When prices are low, the poor financial incentive, combined with security, reliability, and operational concerns, discourages participation.

A data-center operator could engage with a third-party service provider, or a virtual power plant operator, to operate the data center's flexible resources in flexibility markets. This would mean handing over partial control of an asset to an outside party, raising concerns about site security and operational limits. It would also have the advantage of leveraging outside expertise on flexibility markets, and offer some risk-sharing in the context of volatile market prices.

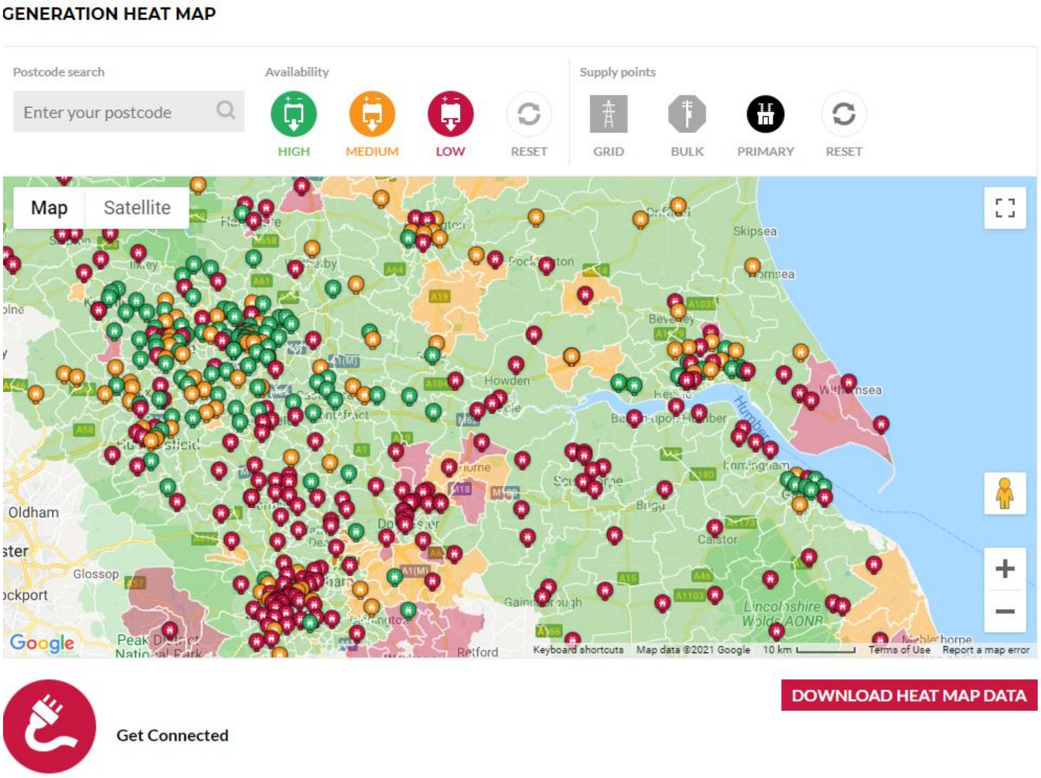
Our take: *Third party service providers or aggregators could help data-center operators overcome their lack of familiarity with power markets and share the risk inherent in market-based pricing mechanisms.*

Data-center operators face long lead times and high costs to secure firm grid-connections

One of the biggest challenges for data-center operators is securing the desired grid connection with the network operator. New connections in areas of congested networks are getting increasingly expensive and longer to complete. As a large electric load, data centers can take up a large amount of available network capacity and the grid operator often needs to reinforce the network, for example by upgrading a substation or building new power lines. Furthermore, data-center operators sometimes want separate grid connections to multiple substations, to ensure redundancy in case one of a substation failure.

Securing network capacity can be a greater challenge for data centers than for other industrial power users, as data centers typically want to locate close to population centers. Network capacity in urban areas may already be limited due to general demand, and upgrading the local infrastructure can be more challenging than in rural areas. Network capacity is already an issue for generation projects in certain areas. In several regions, such as the U.K. and Australia, network operators publish heat maps that shows the available network capacity to connect new projects (Figure 42). A similar tool would help data-center operators to locate new projects.

Figure 42: Northern Powergrid generation network capacity heat map



Source: Northern Powergrid

Applying for and securing a new grid connection can be time-consuming. Assessing, designing, permitting and building a new connection can take years – time that data-center operators may not want to spend. The time expectations between data-center and grid operators are often misaligned.

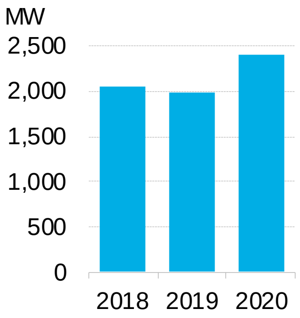
These long lead times are one of the reasons for ‘development’ or speculative connection requests. These requests are a challenge for the grid operator. Companies prepare a site for data-center development: they have the land, apply for planning permission and for the grid connection. It is not guaranteed that the data center will ever be built, but the network operator must consider all connection requests. Such speculative connection requests can occupy network capacity and exacerbate the network operator's capacity constraints. To counteract this, network operators are introducing assessment charges and evaluating projects on the likelihood of completion.

Our take: *Obtaining a grid connection is a key pinch point for data-center operators, which could be leveraged to unlock more flexibility – see following discussion.*

Flexible grid connections

At the time of writing, the Irish energy regulator was consulting on a proposal to prioritize data center connections that were not 100% firm, or where the data center had a proportion of on-site flexibility – be it generation, demand response or storage.

Figure 43: U.K. annual contracted flexible connections



Source: BloombergNEF, Energy Networks Association

This idea has divided stakeholders. Some believe that if this approach was uniform across all data centers or even all large industrial loads – regardless of age – then it would come to be regarded as 'business-as-usual' These so-called 'flexible connections' give system and network operators another tool to help manage their network and reduce infrastructure build-out. They can also reduce connection costs and timelines for new data centers. This approach of non-firm connections are already in use in the U.K. and have been used for 6.4GW of generation – for more details (Figure 43), see *Alternative Connections, Good and Bad for Renewables* (web | terminal).

However, other stakeholders contend that the concept of flexible connections is unfair to new grid users and detrimental to business operations. The application of such arrangements to a specific customer type (ie, data centers) would go against the principle of neutrality, where network operators should treat all grid users equally, as well as moving away from a preferred 'light-touch' model of operation. There is also a concern that a flexible connection is a one-time contract at the time of connection. It would not be able to account for the changing value of flexibility on the grid over time; nor would it be market-based. And if the flexibility requirements were stringent, it might prevent the data center from participating in other flexibility programs.

If a grid operator introduced such an approach of prioritizing a flexible connection, then it would need to develop a method for prioritizing the flexible connection requests. This would ultimately create another queue and a more complex assessment of what flexible resources are considered, and for what flexibility applications. A non-form connection may also lead to the use of more on-site generation, which would more than likely be fossil-fuel based as alternative technologies are still expensive.

Our take: *Discussion of flexible connections grew following the Irish regulator's proposed new data-center connection policy in July 2021. The concept would be a useful tool to manage power systems but are unpopular with data-center operators. While potentially useful, it is a blunt approach that would not properly value the flexibility provided and may conflict with other flexibility services.*

Data-center redundancy and operational awareness

Data centers have spare capacity built into their design, which could be used for flexibility with very little impact on operations. Building component redundancy into data center design ensures service continuity in the event of an individual component failure. This redundancy applies to both UPS and back-up power. There are different redundancy designs, such as "2N" or "N+1". "N" denotes the required capacity, so 2N means installed twice the required capacity. "N+1" indicates extra installed capacity, typically 25% on the requirement. The flexible capacities in Section 3 are based on rack capacity and do not consider redundancy design. This means the actual installed flexible resources are likely higher than our estimates, ranging from 25% to 100% bigger.

Data-center operators find it challenging to forecast computational demand. Hyperscale providers can have some foresight, in particular for their own internal operations, but even then the size of these companies means it is still difficult. Colocation providers have essentially zero visibility on upcoming compute demand and thus energy demand. In most cases, the data-center operator leaves a buffer zone beneath its full computation capacity in case of a surge in compute demand. This means that the backup resources have spare capacity available, above what the data center actually needs at that time. Accessing this spare capacity could be a good testbed for exploring data-center flexibility – but again, this requires better forecasting capabilities to understand the spare energy resource capacity.

Our take: *To maximize flexibility potential, data-center operators will need to develop better load forecasting capabilities. They could also examine redundancy levels in their power resources to determine if some of this could be unlocked for flexibility.*

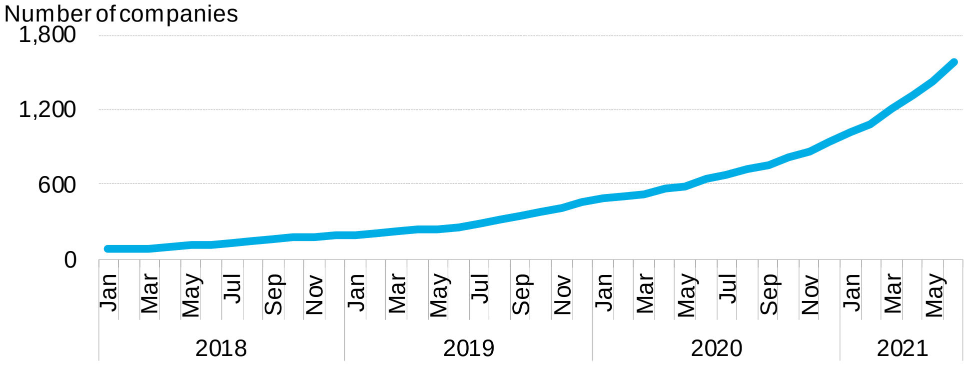
Improving environmental credentials in response to customer demands

Climate change and environmental concerns are spurring data-center operators' efforts in sustainable energy, as they aim to prove to customers and investors that their operations are as 'green' as possible. Operators are already focused on procuring clean energy supply and improving efficiency, and big technology companies are among the leading signatories of power purchase agreements with renewable projects. Some data-center operators, such as Google and Microsoft, are taking the next step in their procurement strategies and aiming to achieve 24/7 renewable energy matching with demand, thus embracing the concept of flexibility.

Matching energy demand with renewable generation will not only reduce carbon emissions but also potentially reduce electricity costs. Low power prices tend to correlate with times of high renewable generation. Data-center operators could use this matching process to improve the terms in their power purchase agreements.

This is part of a wider push by companies across numerous industries: as of July 2021, almost 1,600 companies had joined the Science-Based Targets Initiative to establish an emissions-reduction target in line with the Paris Agreement (Figure 44). The push towards better tracking of data-center emissions appears inevitable and could enable more effective reduction strategies.

Figure 44: Cumulative number of companies that have joined the Science-Based Targets Initiative



Source: BloombergNEF Science-Based Targets Data Tool

Many believe that environmental factors will ultimately drive data centers to adopt greater flexibility. As leaders like Google and Iron Mountain trend towards 24/7 renewables and provide clients with more granularly (eg, hourly) data on energy and emissions, it will become more apparent that flexibility is needed to match data-center operations to power system conditions,

Our take: *Improving efficiency and using renewable energy are good steps for data-center operators to demonstrate their green credentials. The next frontier will be to contribute more broadly to the overall decarbonization of the power system, by being a more active participant.*

Data-center users not exposed to variable energy prices

Data-center customers are typically insulated from energy cost variability. In the case of colocation providers, the data-center operator pays the direct energy costs and then recoups those energy costs through a variety of customer charges. Contract structures vary, but typically include no incentive for the user to vary their demand based on power market conditions. Hyperscale operators can better forecast and control their energy use, allowing them to pursue programs for 24/7 renewable matching.

Our take: *There appears to be some scope for encouraging data-center clients to adjust their usage according to conditions on the grid. This would require innovative contract structures and better transparency on power system conditions and prices.*

TSO-DSO coordination for network management

A country's electricity network consists of both high-voltage transmission networks and low-voltage distribution networks, and their respective operators. Data centers of varying sizes connect to both network types. The two network operators coordinate the connection requests of large loads such as data centers, assess their effect on the network and determine whether any grid reinforcement is required.

Distribution network operators are increasingly playing more of a *system* operator role, actively managing distributed energy resources and operating local flexibility markets. These new approaches can improve renewable integration and reduce the amount of network reinforcement needed, creating a cleaner and cheaper power system. For more on this topic, read *Local Flexibility Markets: A Primer* (web | terminal)

While the distribution system operator (DSO) concept is backed by the European Commission, uptake across Europe has been piecemeal. The U.K. leads in the roll-out of local flexibility markets, with significant progress also seen with the NODES platform across the Nordics and with GOPACS in the Netherlands. However, network operators say that a change to network regulation is needed to encourage the adoption of the DSO concept. Network companies typically earn revenue through regulated returns on the capital they invest. New approaches to management are typically software-based and more of an operating cost. The U.K.'s RIIO regulation framework, which rewards companies based on total expenditure, both capital and operating, has helped to incentivize the growth of the DSO in the country.

A more active role from the DSO means greater interaction with the transmission and system operators (often the same organization). The two network operators must ensure than any action taken by one does not negatively affect the other. Today, DSO actions are too small in scale to have a significant impact on other stakeholders. However, as the concept grows and the DSO makes further actions, the coordination will become more important. It is early days but organizations such as ENTSO-E and the newly formed European body representing DSOs are overseeing these interfaces and collaborations.

4.3. Realizing the potential of data-center flexibility

Grid operators, regulators, data-center operators and data-center users can all take steps to unlock greater flexibility from data centers. Above all, greater collaboration is needed between these parties. The power system and data centers are both sophisticated and critical elements of modern society, and greater dialogue could help to identify opportunities for mutual benefit and the potential steps needed to achieve them.

Here we present the ideas and suggestions that have emerged from our research, on what the stakeholders, regulators and grid operators, and data-center operators and users, can do to enable greater data-center flexibility. Many of these have come directly from stakeholders spoken to for this research report.

Regulators and grid operators

Regulators and grid operators can help create the conditions to encourage data-center operators and users to provide flexibility. These parties agree that there is a need for greater flexibility in the power system due to rising renewables and already taking steps to encourage flexible resources.

Improve flexibility incentives and access to markets

Countries should implement the full measures of the European Commission's Clean Energy Package and the Electricity Market Design. These programs encourage system and grid operators to procure flexibility from distributed energy resources, such as on-site batteries, to avoid overinvestment in physical grid infrastructure. The provisions include creating markets for different flexibility needs, such as congestion management, and removing barriers to entry to these markets, such as minimum capacity thresholds and moving to daily procurement cycles. The EMD also directs network operators to create markets to procure network management services, such as local flexibility markets. These network management markets are still in early stages but could be an added revenue source for distributed energy resources.

More granular settlement periods in wholesale power markets, such as moving from 1-hour to 15-minute periods for financial settlement, can also help. This change would help price flexibility in volatile markets for fast responding resources such as batteries. Evidence from Australia shows that moving from 30-minute to 5-minute settlement periods would have increased one battery's daily revenue by 22%, *Australian Batteries to Benefit From New Settlement Regime* (web | terminal).

Communicate and assign the environmental benefits of flexibility to end users

Environmental and carbon benefits are a strong incentive for data-center operators to provide flexibility. Google and Microsoft's 24/7 renewable matching goals will benefit from flexibility, and similar to how these companies led on corporate renewables purchasing, they could also set the standard for other data-center companies.

To help companies to flex their operations and resources to align with renewable generation, grid operators could communicate hourly emission intensity data, which is not standardized in many regions. With this emissions data, data-center operators and users could schedule compute tasks or energy resources to reduce their Scope 2 emissions.

Battery storage and demand response can provide system services, such as frequency reserves, and offset the use of fossil fuel generation. A standardized assessment of this carbon benefit and attribution would encourage data-center operators, and their users, to use their resources, such as UPS, in system-services markets.

Use new connection and planning rules to encourage data-center flexibility

Regulators and grid operators can use connection and planning requirements to shape data centers' operation. One example of this is the Irish regulator's proposed directive to prioritize data-center connections that can be interrupted at times of system constraints.

When considering new grid connection applications, grid operators could offer non-firm connections as an option with reduced cost and time to complete the connection.

Network companies could publish the available capacity on their networks. This would help data-center developers to identify the areas where capacity is available and reduce connection requests to particular stressed areas of the network.

Planning applications could require a proportion of on-site flexibility. The required value would be set and data centers would have freedom in the technologies to meet this requirement. This is similar to the 'Merton rule' introduced in U.K. local authority of Merton, which required that new buildings cover a certain proportion of their electricity demand with a renewable energy source. This planning requirement was effective in encouraging on-site renewable installations.

Data-center operators

Data-center operators can take steps to increase the flexible operation of their own resources and users.

Run trials and pilot projects to understand the potential of flexibility

Data-center operators have little experience with power system flexibility and need to build confidence in the concept. A series of trials or pilots would explore the potential capacity within data centers, looking resource by resource to understand their true potential, and address operators' concerns about impact on performance. Information sharing amongst data-center operators would be key to build awareness within the industry. Greater collaboration between all the parties involved and improved communications. There are many lessons to learn, such as which party is at risk, who is responsible and who benefits. This may also require some sand-boxing or ring-fencing to avoid breaching existing commercial contracts and service-level agreements.

Explore how to incentivize user load shifting

Data-center operators could charge users varying energy prices throughout the day to reflect power market conditions, similar to some tariffs offered by energy suppliers to their customers. So called time-of-use tariffs charge the user a different value for their electricity use at different times of the day. Time-of-use tariffs incentivize the user to shift load to the times of lowest cost and reduce the need for energy balancing or renewable curtailment. Time varying tariffs come in many forms from fixed prices depending on the time of day to full wholesale price pass-through to the user. The data-center operator would also need a similar time-of-use tariff with their energy supplier if they are to reflect this to the data-center users.

There may also be other innovations that could be explored regarding fee structures, such as lower fees for customers willing to have some loads shifted, or higher tariffs badged as greener, to help cover the costs of flexibility.

Track and communicate carbon emissions to users

The data-center industry lacks transparent data on energy use or emissions. Tracking this data would allow the industry and users to better understand their environmental impact: the more granular the measurement period the better, such as every 15 minutes. This would be similar to Google and Microsoft's 24/7 renewable matching ambitions – data-center users could then adjust their computation scheduling to minimize carbon emissions.

Exposing data-center users and software engineers to this data could encourage a greater understanding by these parties and design of software and applications to be flexible to these carbon emissions signals. Ultimately, software engineers could even design their applications to be delay-tolerant or respond to real-time market signals.

Section 5.

Summary of country–level drivers and market dynamics

Section 5. Summary of country-level drivers and market dynamics

In this final section, we provide an overview of the key issues facing the five focus countries covered in this report – Norway, the Netherlands, Ireland, Germany and the U.K. – and the main opportunities and challenges they face.

5.1. Pursuing digital growth alongside the climate imperative

Many countries highlight the importance of the digital economy for future development and prosperity, and the EU has declared the 2020s as Europe's digital decade. A key component for this digital economy will be the data centers required to store and process the vast amounts of data that will be created. The European Commission also states that this digital transformation is critical to achieve the transition towards a climate-neutral, circular and resilient economy. It is important then that the development of the digital infrastructure for this digital transformation should be climate-responsible, and compatible with a net-zero energy system.

Even as countries develop their net-zero climate strategies, many are also building out their own digital strategies, where data centers are a key component. It is not an exaggeration to say that the growth of the digital economy and the transition to net zero will be two of the most important opportunities to be captured in the first half of the 21st century.

At the same time, the development of data centers in Europe has alarmed several stakeholders: local authorities, grid operators, regulators and the public – and for fair reasons. Data centers use large amounts of energy, water and land, which puts pressure on local and regional resources. In Europe, we have seen several examples of pushback against data-center development – a moratorium on development in Amsterdam, new development policy in Frankfurt and signals from the Irish grid operator to move data-center development away from the Dublin area.

Furthermore, data-center developers have some freedom in choosing where to site their facilities and can look across different countries and regions to make their choice. This means there is an element of competition in attracting investment, and countries have the opportunity to secure the economic rewards by creating a favorable environment. Data centers tend to look at several factors for site selection:

- Land availability and cost: data centers cover a large area
- Electricity network capacity: a reliable and cheap connection to the grid
- Energy costs: a reliable and cheap supply of electricity
- Telecommunication network capacity: a reliable and high-quality network, such as fiber- optic cable
- Water supply: data centers may need large amounts of water for cooling
- Proximity to users: improve the quality of service such as low latency
- Safety from natural dangers such as flooding or seismic activity

Finally, access to clean electricity is rapidly becoming a key factor, as data-center operators face pressure to decarbonize their operations.

European Union data center and flexibility policy

The European Commission has labelled this decade as Europe's 'Digital Decade'. As part of this initiative, the Commission set several digital goals, which includes a target for 75% of EU companies using cloud or artificial intelligence technology. At the same time, the commission has set ambitious renewable and carbon emission targets, stressing that the growth in digital must align with these climate-change goals. More data centers will be needed to meet these digital goals. In 2020, it published a report that estimated data centers in the EU will consume 3.2% of electricity demand in 2030, up from 2.7% in 2018.

The Commission wants to align its digital and green ambitions and has focused on data center efficiency. In 2008, the Commission established a voluntary Code of Conduct for Energy Efficiency in Data Centres, which establishes best practice guidelines for efficient data-center operation. The Commission's Ecodesign initiative grades and sets standards for servers and data storage equipment and introduces product design requirements for products sold in the EU, such as minimum power efficiency. The initiative also touches on the potential for data centers to act as a source of grid flexibility but does not go into further details.

Following on from these efficiency policies, in July 2021 the Commission proposed that member states collect and publish information on data-center energy and water use. The proposed 'sustainability indicators' will track a data center's efficiency, use of renewable energy, reuse of waste heat and use of water. The proposal intends to raise awareness and bring transparency to the sector, though some data-center operators may push back as this information is often considered commercially sensitive.

Data-center operators do acknowledge the need for sustainable data centers and following the 2019 European Green Deal, several operators and associations formed the Climate Neutral Data Centre Pact. Signatories to this self-regulatory initiative pledge to achieve several sustainability-linked goals, such as minimum power and water usage effectiveness, and clean energy use targets.

As part of the EU's digital plans, the Commission wants to establish an EU digital single market, to ensure that data can move freely and safely between member states. This may mean barriers to non-EU members such as Norway and the U.K. for those data centers to serve users in the European Union.

The Clean Energy Package and Electricity Market Directive lay out various measures to improve flexibility in Europe's power system. Such measures include passing real-time signals from the wholesale power markets to consumers to encourage load shifting, create markets for system services and reduce barriers to entry to for distributed energy, and moving to more granular and frequent power and system-service markets.

5.2. Country comparison

All the factors mentioned above vary across the five countries covered in this report, but here we focus on the energy-specific ones, namely:

- Cost: retail and wholesale electricity prices
- Reliability: grid outage metrics
- Sustainability: grid carbon-emissions intensity

On these three factors, no one country is the stand-out location for data-center development. Norway is the strongest on two dimensions, as it has the lowest emissions intensity and power prices due to abundant hydropower – but it scores the lowest on grid reliability (though this may not be representative, as we discuss below in the Norway section).

Cost

Germany and the U.K. have the highest retail power prices for large energy users (Figure 2). In terms of wholesale energy market prices, the spread between the countries is small, with the exception of Norway. The difference between the wholesale and retail prices is due to network charges and levies applied to the retail tariffs.

Figure 45: Semi-annual retail electricity prices for large energy users

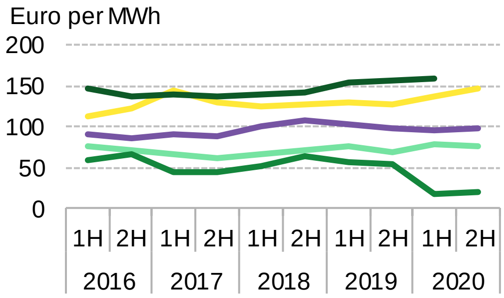
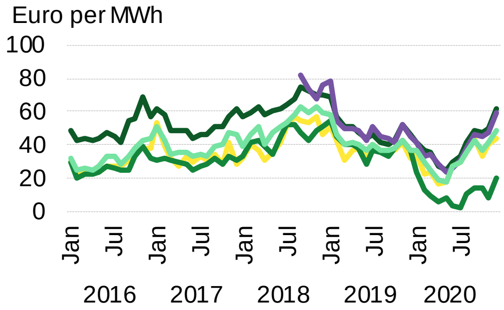


Figure 2: Average monthly wholesale prices



Source: Eurostat. Note: including all taxes and levies for users consuming between 70GWh and 150GWh a year

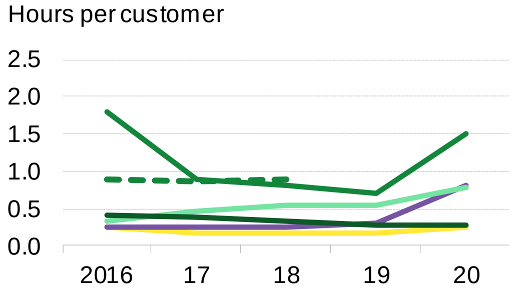
Source: Bloomberg Terminal. Note: U.K. values are for the Great Britain wholesale power market. Norway is the Nordpool market.

Reliability

Reliability of power supply is a key concern for data-center operators, which is why they have sophisticated back-up power systems. Most service interruptions are due to faults in the network infrastructure (rather than generation shortfall), which means interruptions are typically a localized issue. When designing back-up power systems, data-center operators want to know the frequency and duration of blackouts at particular parts of the grid. This will influence the size of back-up power installed as well as the fuel storage for its back-up generation. System-level interruptions, such as due to lack of supply, are less frequent but the impact can be greater and wider than network-related interruptions.

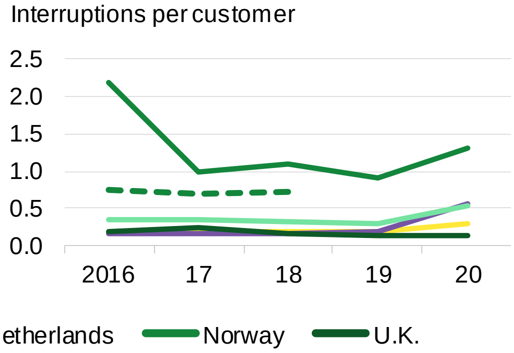
There are two common metrics for reliability, known as the system average interruption *duration* and *frequency* indexes, which respectively measure how much time a user can expect to be without power in a year, and how many such events typically occur. European power systems are some of the most reliable in the world and countries such as the U.K. and Germany score highly on reliability metrics. Norway does not score as well on reliability relative to the other countries as it has a dispersed population and far-reaching network; however industrial users enjoy better reliability than remote communities. For this reason, we include a reliability metric for industrial consumers developed by SINTEF, a Norwegian research group, in the comparison in below (Figure 47 and Figure 48).

Figure 47: System average interruption duration index (SAIDI)



Source: World Bank, SINTEF, BloombergNEF. Note: Dashed line indicates SAIDI score for Norwegian industrial consumers.

Figure 48: System average interruption frequency index (SAIFI)



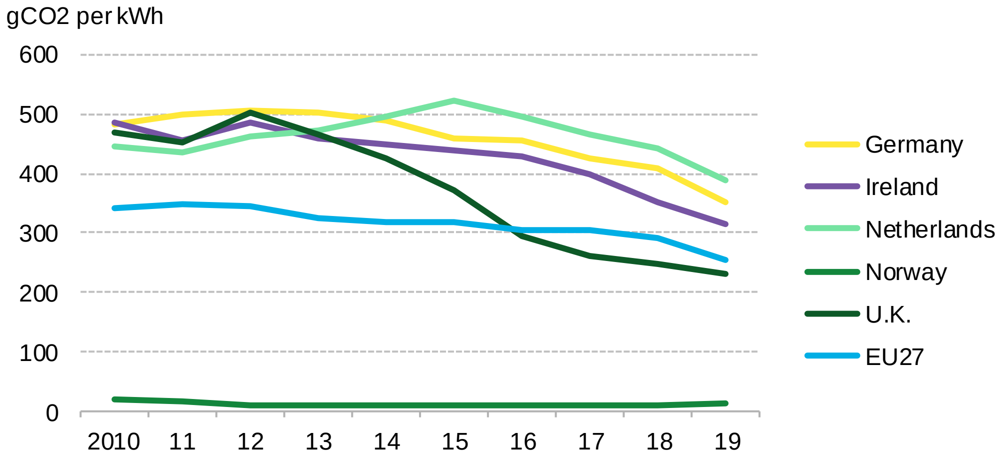
Source: World Bank, SINTEF, BloombergNEF. Note: Dashed line indicates SAIFI score for Norwegian industrial consumers.

Sustainability

Across Europe, countries have been installing renewable generation and reducing the average grid emissions intensity. The U.K. has made impressive progress in this effort, halving its grid intensity to 230gCO_2 per kWh in 2019, from 470gCO_2 per kWh in 2010. The other focus countries have also reduced their grid intensities. This decline reinforces the argument for decarbonization through electrification. The challenge for system operators, regulators, politicians and the public is to maintain (and even accelerate) the intensity decline while at the same time ensuring costs and reliability do not deteriorate.

On this metric, Norway is by far the best performer, with near-zero carbon emissions in its power system.

Figure 49: Annual average grid carbon-emissions intensity



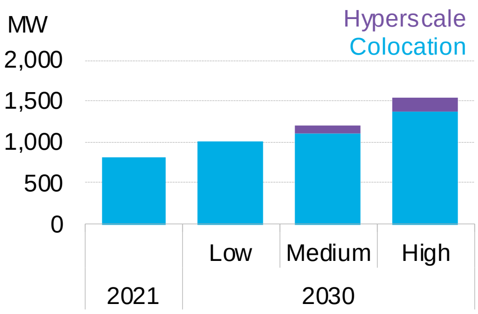
Source: European Commission, BloombergNEF

5.3. Germany

The majority of Germany's large data-center capacity is located in and around the city of Frankfurt. Frankfurt draws data centers due to its large financial sector, its proximity to neighboring countries and the Deutscher Commercial Internet Exchange (DE-CIX) located in the city – one of the largest internet exchanges in the world. Despite the high capacity, German data centers account for only 1% of the country's total annual electricity demand (Figure 50), which is low relative to other markets, such as the Netherlands (5%) and the Ireland (14%).

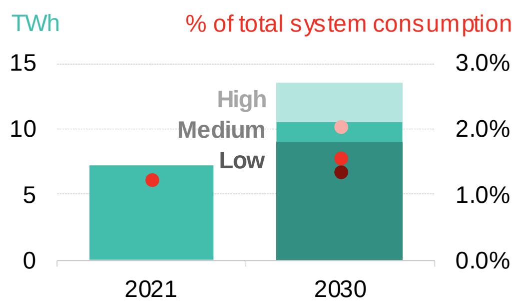
We expect the live IT power to grow 46% from 2021 to 2030 in our medium growth scenario – a significant level of expansion, but still the lowest of the five focus countries. This is because Germany is a mature data-center market, led primarily by colocation operators. Higher growth rates could be possible if hyperscale operators grew their presence in the German market, but this would be a departure from today.

Figure 50: Germany data-center live IT capacity by growth scenario



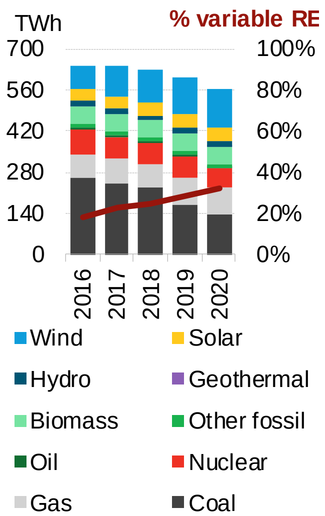
Source: BloombergNEF

Figure 51: Germany data-center electricity use by growth scenario



Source: BloombergNEF

Figure 52: German generation mix



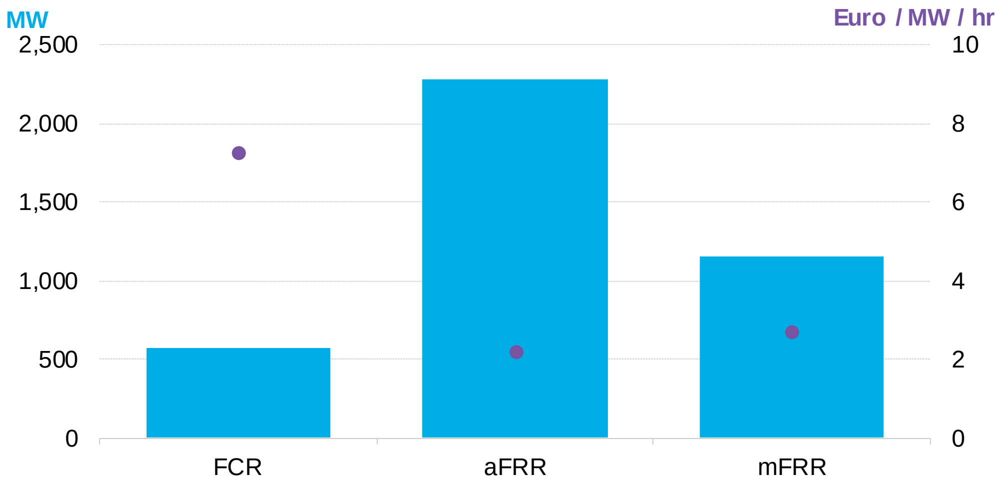
Source: BloombergNEF.

German data-center capacity has grown despite paying some of the highest electricity prices in Europe (Figure 45). Unlike other energy-intensive industries in Germany, data centers are not exempt from paying taxes and levies associated with climate-change policy. From an environmental perspective, Germany's grid emissions, at 350gCO2 per kWh, are greater than the European average, though this number should continue to fall with the phase-out of the country's coal generation. But while the German grid underperforms in terms of cost and sustainability, it scores very well on reliability metrics.

The German power market has gone through many changes in recent years, most notably its pledge to phase out its nuclear fleet by 2022 and more recently to phase out its coal fleet. At the same time, Germany achieved a wind and solar penetration rate of 32% in 2020 (Figure 52). Interconnectors are a good source of flexibility though German system operators will need to procure more flexibility to tackle issues such as constraint management. Germany has 31GW of interconnection capacity to neighboring countries, which could meet 39% of the country's peak load in 2020. This value compares to 13% for the U.K. (7.4GW) and 18% for Ireland (1GW).

Germany's large power system means that its system operator procures large amounts of system services. To improve its flexible capabilities, the German system operator is expanding its redispatch program to include lower capacity power plants and integrating its system services with its neighboring countries. An example of the latter is the FCR Cooperation where the system operators of several European countries procure their frequency containment reserves (FCR) in a common market. Similar projects are in progress to consolidate markets for other system services such as PICASSO for automated frequency restoration reserve (aFRR) and project TERRE for replacement reserves. The fast-acting FCR offers the highest value of the German system services and suits data-center flexible capabilities (Figure 53).

Figure 53: German average 2020 contracted capacities and prices for system services



Source: BloombergNEF, Tennet, Regelleistung.

German flexibility markets are expected to develop in the years to come. The German Energy Agency (DENA) identified several key areas of development, such as providing instantaneous reserve (ie, inertia) and managing reactive power[6]. Batteries located in data centers can provide the flexibility for these fast-acting services. However, as of writing, the Germany system operator does not procure such services.

As with other countries with a large data-center presence, such as Ireland and the Netherlands, there has been some pushback against data-center development in Germany. In May 2020, a Frankfurt local magistrate called for a development plan to manage new data-center development. Several factors led to the magistrate's report, including energy and network concerns, though land use and use of commercial space featured prominently. The development plan has not yet been finalized, though initial proposals include mandating minimum power usage effectiveness and data-center infrastructure efficiency values, encouraging the productive use of waste heat, and ensuring that development is in line with the municipalities' climate change mitigation plans. The proposed development plan is similar to the new policies introduced in the Amsterdam area.

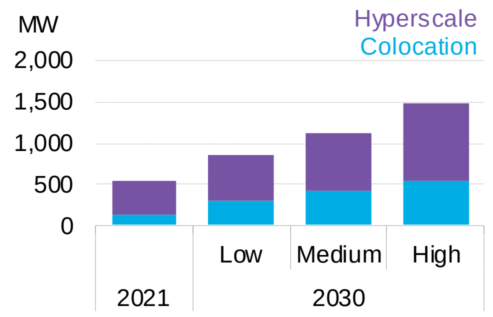
5.4. Ireland

Ireland has seen huge data-center build-out, led by hyperscale companies such as Google and Microsoft. Irish data centers will use around 15% of the system's total electricity consumption in 2021 – the highest proportion of the focus countries. This is expected to rise to 24% in 2030 under our medium growth scenario. Data centers are a contentious topic in the country. The large

[6] DENA, Innovation Report Ancillary Services, December 2018

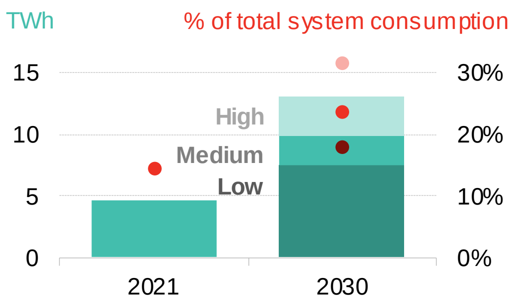
data-center build relative to the size of the power system has put strain on the available network capacity, particularly in the Dublin area, and raised concerns about security of supply and achieving climate change goals. Those goals include reaching net-zero carbon emissions by 2050 and achieving 80% of electricity demand from renewable energy sources by 2030, as set out in the government's renewed National Development Plan.

Figure 54: Ireland data-center live IT power by growth scenario



Source: BloombergNEF

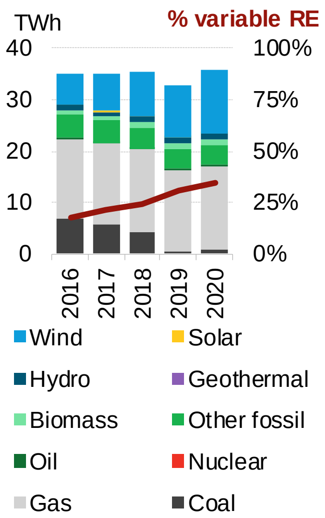
Figure 55: Ireland data-center electricity use by growth scenario



Source: BloombergNEF

In July 2020, the system operator, Eirgrid, issued the Data Center Connection Offer Process & Policy (DCCOPP) to update the data-center connection process [7]. The policy intended to push data-center development to less constrained parts of the network and to encourage flexibility in constrained areas. In June 2021, the Irish energy regulator, the Commission for the Regulation of Utilities (CRU), issued a consultation on data-center connections and proposed a method to prioritize connection requests which could be flexible[8].

Figure 56: Ireland generation mix



Source: BloombergNEF. Note: RE refers to renewable energy

Several organizations have issued responses to the consultation, raising concerns about the proposal. IDA Ireland, the agency responsible for attracting foreign industrial investment to the country said that the proposed approach could limit future foreign investment. The Energy Association of Ireland says that the growth in data centers and their electricity demand has been forecast for years and believes that supply concerns could have been dealt with sooner. In a reported IDA briefing, data-center operators in Ireland believed that Eirgrid's projections over-estimate data center's future electricity demand. Eirgrid has forecasted data-center use as 23% of total electricity consumption in 2030, while this research estimates the proportion to be around 24%.

Ireland has attracted a lot of hyperscale development due to a history of North American technology companies locating in the country – both Google and Apple's European headquarters are in Ireland. Other supporting conditions include strong telecommunication links to North America and Europe, a skilled workforce and a favorable business environment. In terms of energy, electricity prices are not too high and the grid is as reliable as others in Europe. While Ireland's grid is still more carbon-intensive that the European Union average, it has a large wind generation capacity and at 34% in 2020 (Figure 56), the highest proportion of variable generation

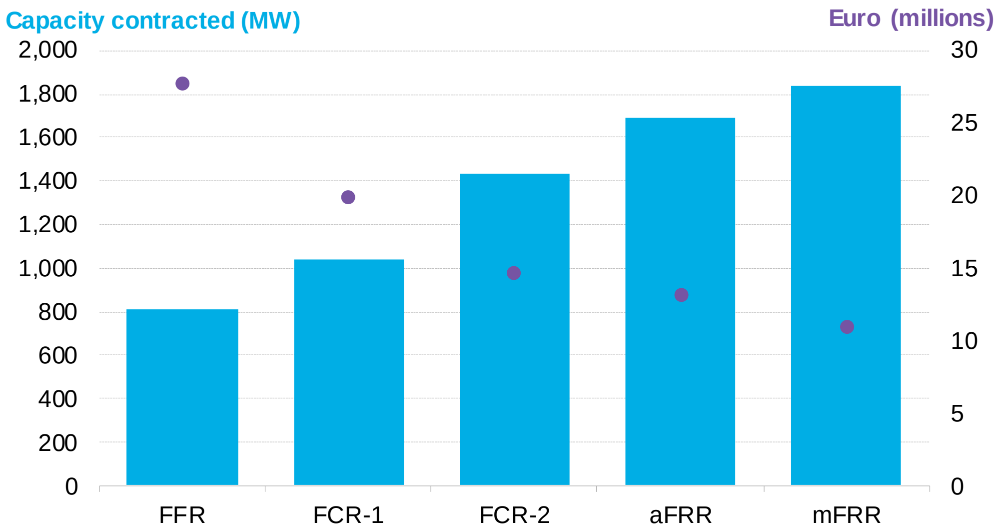
[7] Eirgrid, Data Center Connection Offer Process & Policy, July 2019

[8] Commission of Regulation of Utilities, CRU proposed Direction to the System Operators related to Data Centre grid connection, June 2021

of the focus countries. The large wind capacity gives data-center operators plenty of options for renewable power purchasing.

To reach higher levels of variable renewable generation, up to 75%, Eirgrid and the System Operator of Northern Ireland established the Delivering a Secure, Sustainable Electricity System (DS3) program. The DS3 program created a range of new products to procure system services such as fast frequency response, ramping requirements, inertia and reactive power. The per-megawatt value for faster-acting services is greater than for slower, longer duration services (Figure 57) and are well-suited to data-center flexible capabilities.

Figure 57: Total contracted capacities and forecasted expenditure for selected system services October 2020 to September 2021 in Ireland



Source: BloombergNEF, Eirgrid. Note: Values are for total capacities contracted, not capacities activated, and for total expenditure. FCR-1 = primary operating reserve, FCR-2 = secondary operating reserve, aFRR = tertiary operating reserve 1, and mFRR = tertiary operating reserve 2.

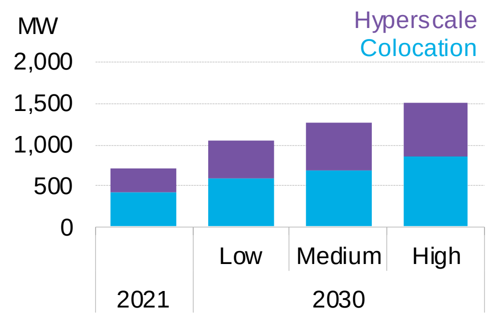
Ireland is an isolated power system, with 1GW of interconnection to the U.K., and has high renewable penetration. This means the system operator faces a challenging situation unlike any of the other countries covered, for which it uses several mechanisms to ensure system stability. For example, Eirgrid requires a 'Minimum Generation' (Min Gen) of 1,400MW of conventional fossil-fuel generation to be running at all times.

Data centers' flexibility could be a tool to reduce the Min Gen requirements and increase renewable penetration. The CRU's proposed flexible connections would force the use of this flexibility, but data-center operators are reluctant to adopt such a measure. In the current situation, data centers must offer some flexibility if Ireland is to continue to build data centers, and achieve its renewable and climate change targets.

5.5. Netherlands

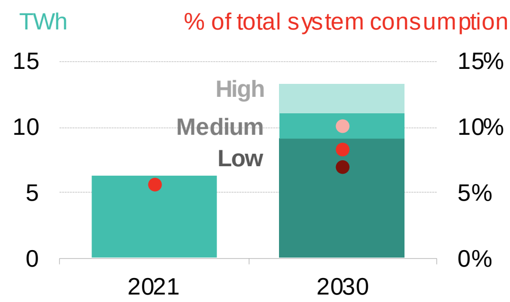
Hyperscale expansion has been the main driver behind the growth of data centers in the Netherlands in recent years. That growth may slow in the years to come, in no small part due to the July 2019 year-long moratorium on new data centers in the Amsterdam area (discussed below). We predict Dutch live IT power to increase 80% by 2030 (medium growth scenario), which, though large, is the second smallest increase of the focus countries after Germany. Dutch data centers represent a large load relative to the size of the power system, using 6% of total electricity in 2021 and rising to 8% by 2030 in the medium growth scenario, though this rises to 10% in the high growth scenario (Figure 58). In response to this rising electricity use, new data centers must achieve a minimum power usage effectiveness of 1.2.

Figure 58: Netherlands IT power by growth scenario



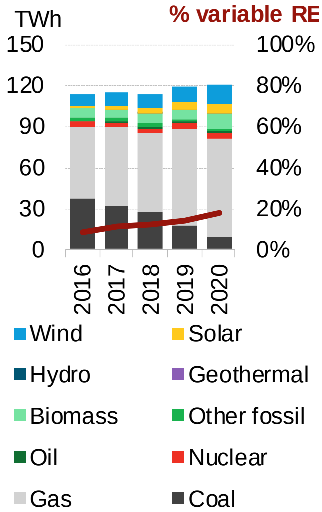
Source: BloombergNEF

Figure 59: Netherlands data-center electricity use by growth scenario



Source: BloombergNEF

Figure 60: Netherlands generation mix



Source: BloombergNEF

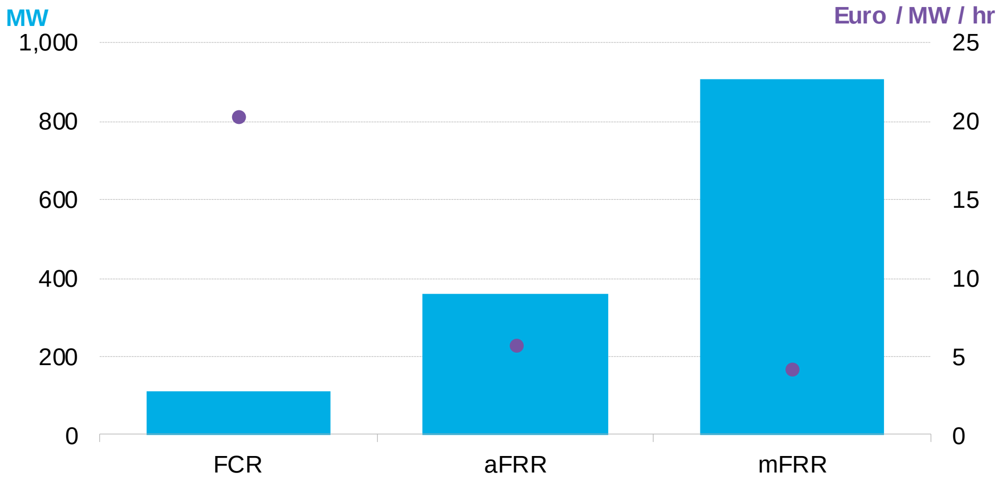
The Netherlands has one of the cheaper electricity prices of the focus countries and its grid is as reliable as Ireland's. The country performs the worst of the five countries on sustainability, with a grid carbon-intensity of 390gCO_2 per kWh in 2019. The low proportion of variable renewables and the large capacity of gas generation (Figure 60), along with 7,850MW of interconnection, means that flexibility is not yet the challenge it is in other regions. The Dutch system operator, Tennet, is still keen to access flexible capacity and sees the greatest need for flexibility at a daily or hourly level to help match variable renewable generation. One example of Tennet's flexibility initiatives is the GOPACS platform, which taps distributed energy resources to solve local network constraints.

In terms of interconnectivity, the Netherlands has good communications infrastructure and is well located to serve neighboring countries. A 2021 report by the Dutch Authority for Consumers and Markets[9] found that Amsterdam Internet Exchange (AMS-IX) has increased in capacity and in 2020 was able to process a peak of 9 terabyte per second (TBPS), up from 3TBPS in 2015.

Netherlands procures its FCR services on the same common market as Germany, though Dutch prices can be higher due to cross-border constraints (Figure 61). The relative size of the data-center market to the power system means that potential flexible capacity is greater than the FCR capacity procured. The Netherlands has not yet launched a fast frequency reserve product like the U.K. or Ireland.

[9] Authority for Consumers and Markets, IP Interconnection market study 2021, July 2021

Figure 61: Netherlands average 2020 contracted capacities and prices for system services



Source: BloombergNEF, Tennet, Regelleistung.

In July 2019, the municipal authorities of Amsterdam and Haarlemmermeer announced a moratorium on new-build data centers in their districts. The municipalities took the surprise decision due to the amount of land and the amount of network capacity that data centers were taking up. The year-long ban ended with several new policy measures in place:

- Designated areas will be earmarked for data-center development
- The pace and capacity of new data centers will be limited to a total of 750 MVA (713MW) in Haarlemmermeer and 670 MVA (637MW) in Amsterdam by 2030[10]
- New data centers must adhere to a minimum power usage effectiveness value of 1.2
- Data centers must explore the use of waste heat for heating nearby homes
- New projects should use multiple floors if possible

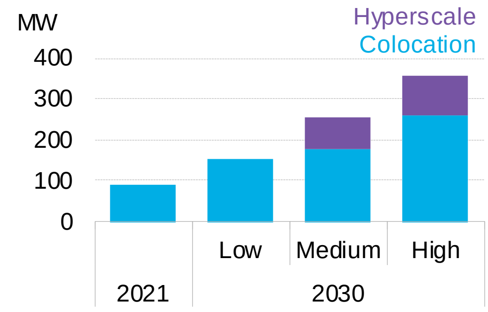
The moratorium and consequent new policies have encouraged development in other areas of the Netherlands. The issues in the Netherlands are similar to those in Frankfurt: the rapid pace of data-center development, limited planning controls on new data-center locations, the use of land, and constrained network capacity. Other less-developed regions should heed these concerns to avoid similar reactionary policies.

[10] Mega volt-ampere (MVA) rating is a measure of electricity network capacity. We can convert to megawatt (MW) capacity by assuming a power factor of 0.95.

5.6. Norway

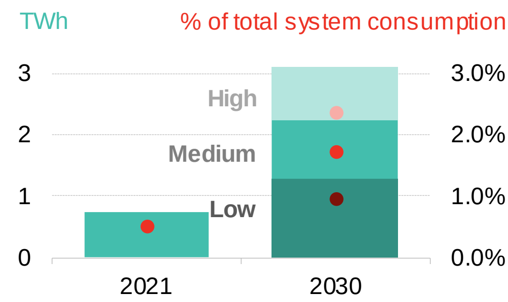
Norway sees the largest data-center growth of the focus countries, with live IT power increasing over 200% in the medium growth scenario (Figure 63) from a small base. Still, Norway's data centers account for a small proportion of electricity demand, suggesting that there is room to grow. Norway's system operator, Statnett, is even more bullish about data-center growth and predicts 5TWh energy consumption by 2030 in its long-term market analysis[11].

Figure 62: Norway data-center live IT capacity by growth scenario



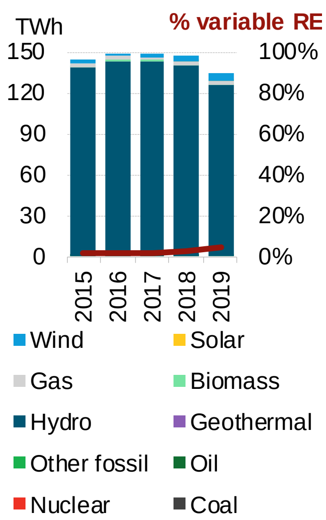
Source: BloombergNEF

Figure 63: Norway data-center electricity use by growth scenario



Source: BloombergNEF

Figure 64: Norwegian generation mix



Source: BloombergNEF

Norway is well placed to host more data centers from an energy perspective. It has the lowest power prices of the five focus countries and is one of the cleanest power systems in the world at ~10gCO2 per kWh. The large amount of hydro generation (Figure 64) means that data-center operators would not need to worry about 24/7 renewable energy matching as this is practically the status quo. Grid reliability can be a concern, though its low reliability indicators also reflect the far-reaching network to a dispersed population. Information on grid reliability by specific region would mitigate data-center operators' reliability concerns.

Where Norway lags in attracting data-center development is its distance from dense populations and limited interconnectivity. The country does not have the same telecommunications infrastructure as the other focus countries. The Norwegian government is investing to improve the country's interconnectivity.

Norway is already home to several other energy-intensive industries, such as aluminum smelters, attracted by the low power prices. New data centers would help to diversify industrial electricity use and strengthen long-term power demand. The added energy demand from data centers will require some investment in generation and network capacity. There are concerns in Norway about a potential future rise in electricity prices due to these investments.

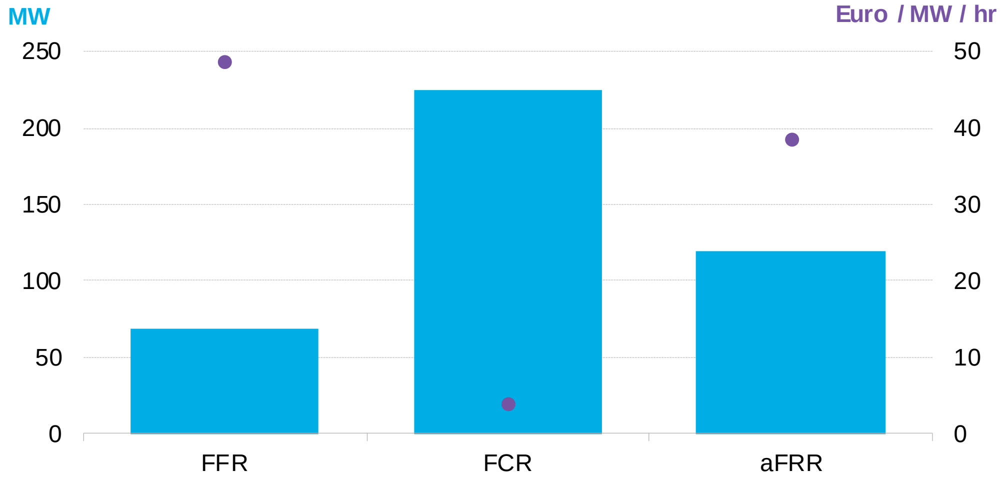
Norway's hydro generation capacity provides it with sizable supply and flexibility. However, Statnett, the system operator is keen to procure greater flexibility. The country is increasing its variable renewable generation, deploying 3,670MW of wind generation by 2020. It is also building more interconnectors with other countries, such as the 1.4GW North Sea Link to the U.K. and 1.4GW NordLink with Germany.

Statnett believes these developments will reduce inertia on the power system, which is important in maintaining the 50Hz frequency, and so in 2021 it tendered for 150MW of fast frequency

[11] Statnett, Long-term Market Analysis 2020-2050, July 2021

reserves (FFR), spread across two products: 50MW of FFR Profile and 100MW of FFR Flex. Statnett awarded 51.8MW and 68.3MW of capacity for FFR Profile and FFR Flex, at a price of 48 euro per MW per hour and 11 euro per MW per hour. Data-center UPS are well suited to provide such fast-acting services, which have short activation durations of 30 seconds. UPS suit for FFR products due to the low levels of battery cycling.

Figure 65: Norwegian ancillary market average 2020 contracted capacities and prices



Source: BloombergNEF, Statnett. Note: FFR refers to FFR Flex. FCR refers to day-ahead primary reserve. aFRR refers to secondary reserves.

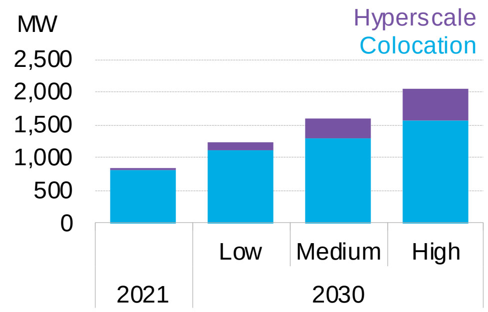
The Norwegian government wants to draw more data-center development and in August 2021 launched its data center strategy with a focus on sustainability. The report lays out the benefits of Norway's power system and highlights support schemes through its Enova program to sponsor low-carbon data centers. The government addresses the limited digital infrastructure and points to several new cables connecting to North America, the U.K. and Denmark. While this will increase the interconnectivity with other regions, the report admits that Norwegian data centers will not be suited to compute that requires particularly low latency.

5.7. United Kingdom

The U.K. is one of the largest data-center markets in Europe and will remain so over the coming decade[12]. Colocation operators account for 98% of U.K. data-center capacity in 2021 and are based around London, drawn by the financial industry. We expect the live power to grow to 1,600MW by 2030, up from 800MW in 2021, according to the medium growth scenario. This is the largest capacity of the five focus countries in 2030. Hyperscale operators are the growth story in the U.K., increasing to 310MW (medium scenario) and potentially up to 480MW (high scenario) of live power in 2030, up from 25MW in 2021. Data centers will account for 2.5% of the U.K.'s electricity consumption in 2021, which will rise to 4.5% in 2030, in the medium growth scenario (Figure 66). While 4.5% is high relative to Germany and Norway, it is far below Ireland's 24%.

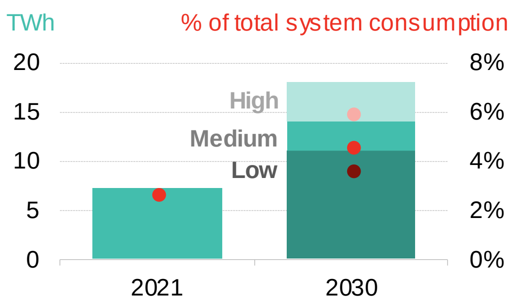
[12] For this discussion and analysis, U.K. refers to mainland Great Britain, which is considered a single power system

Figure 66: U.K. data-center live IT power by growth scenario



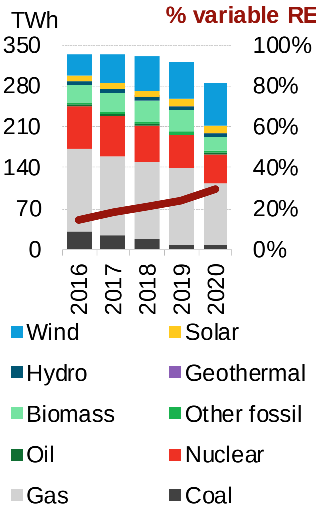
Source: BloombergNEF

Figure 67: U.K. data-center electricity use by growth scenario



Source: BloombergNEF

Figure 68: Great Britain generation mix



Source: BloombergNEF

The system operator, National Grid ESO, has not expressed specific concern about data-center electricity demand. The term 'data center' does not appear in National Grid ESO's 296-page *Future Energy Scenarios*[13]. In comparison, 'data center' appeared 26 times in Ireland's 92-page *All-Island Generation Capacity Statement 2020-2029*[14]. As with all the focus countries, network operators find it difficult to accommodate all data-center connection requests, particularly in the London area.

Like Germany, the U.K. has high power prices and a reliable grid. However, the U.K. has a far better grid carbon intensity, reaching 230gCO_2 per kWh in 2019. This is the second-lowest value of the focus countries (Norway's grid is the cleanest), and a steep fall from 500gCO_2 per kWh in 2012. This reduction came from a quick winddown of coal power plants, ahead of the 2025 phase-out deadline, and rising wind power. While closing coal plants, the U.K. has built 22GW of renewable capacity and now variable generation serves almost 24% of the country's electricity needs. This high proportion of renewable generation, and only 7.4GW of interconnection capacity, or 13% of peak load, creates flexibility challenges for the system operator.

The U.K. is considered ambitious in its flexibility efforts, which would bode well for flexible data centers. The system operator is taking several steps to update its system services and balancing mechanisms. This includes reducing minimum bid size for products, removing barriers to entry for aggregators and virtual power plants, and moving products to daily procurement cycles. More specifically, National Grid ESO launched a sub-second fast frequency reserve (FFR) product, Dynamic Containment, for which it aims to procure 1.2GW of capacity (Figure 69). Participants find the FFR prices attractive, but the specifications and control requirements for this new service can be onerous and so far, only utility-scale batteries participate.

The energy regulator Ofgem intends to separate the system operator role out of National Grid PLC, which also operates the transmission network. One of the reasons is to avoid bias at the system operator between pursuing conventional wire-based and new non-wire solutions. The U.K.'s large data-center capacity, and its inherent flexibility, can be part of these new solutions for a renewable grid.

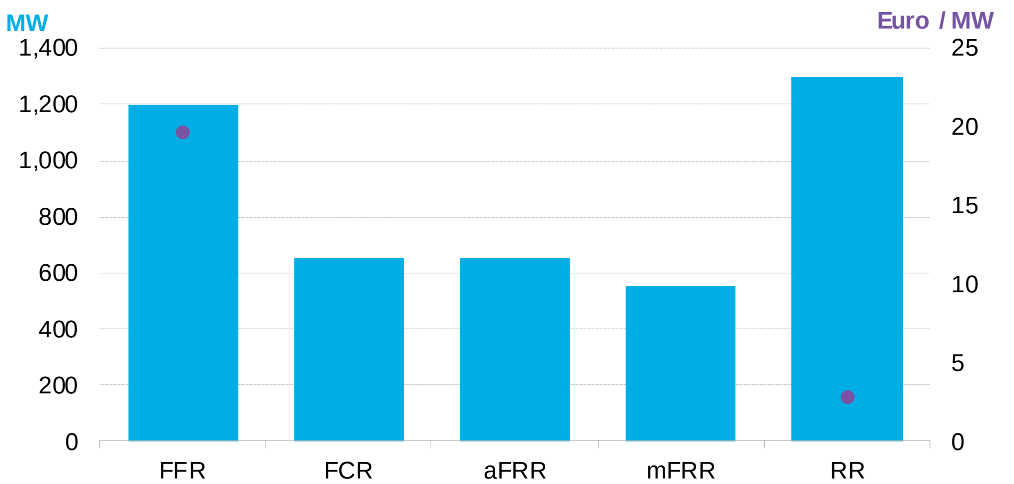
The system operator, and the network operators, are pursuing new approaches to manage the system and networks, which bodes well for data-center flexibility. These new approaches are

[13] National Grid, Future Energy Scenarios, July 2021

[14] Eirgrid, All-Island Generation Capacity Statement 2020-2029, August 2020

possible due to the U.K.'s RIIO (Revenue = Incentives + Innovation + Outputs) regulation, which rewards network operators based on their total spending and performance, as opposed to the capital expenditure, which favors investments in conventional grid-infrastructure.

Figure 69: U.K. average 2020 contracted capacities and prices for system services



Source: BloombergNEF, National Grid. Note: FFR = Dynamic Containment, FCR = firm frequency response (primary), aFRR = firm frequency response (secondary), mFRR = firm frequency response (high) and RR = short-term operating reserve.

U.K. distribution network operators, which operate the low-voltage grid, are actively exploring new approaches to managing their networks. These new approaches are part of their efforts to become distribution system operators (DSO). The grid companies have launched local flexibility markets and by the end of 2020 had contracted 4.4GW of flexible capacity. DSOs use local flexibility markets to access distributed energy resources such as batteries or demand response, to reduce strain on specific parts of their network. This is an increasingly viable alternative to building additional network infrastructure. For more on the topic read *U.K. Local Flexibility Markets: A Case Study* (web | terminal).

Appendices

Appendix A. Data-center capacity forecast growth assumptions

The report forecasts the growth of installed data-center design capacity for Germany, Ireland, Netherlands, Norway and the U.K. The growth assumptions are based on research and interviews with industry stakeholders.

Table 17: Data center growth assumptions

Location	2024	2030		
		Medium	**Low**	**High**
Germany	Announcements + raw numbers based on what may or may not get built, planning permission, companies said to have plans in that region etc. Low, medium and high scenarios adjusted raw data for each, no percentages.	Colocation = 4% + 60MW announcements for build	Colocation = 2.5%	Colocation = 7% Hyperscale = +130MW
Ireland		Colocation = 7% Hyperscale = 6%	Colocation = 4% Hyperscale = 4%	Colocation = 9% Hyperscale = 10%
Netherlands		Colocation = 5% Hyperscale = 8%	Colocation = 3% Hyperscale = 5.5%	Colocation = 8% Hyperscale = 9.5%
Norway		Colocation = 6.5% Hyperscale = 3%	Colocation = 5.5%	Colocation = 11% Hyperscale = 4.5%
U.K.		Colocation = 4.5% Hyperscale = 6% + 150MW	Colocation = 2.5% Hyperscale +100MW	Colocation = 6.5% Hyperscale = 9% + 200MW announcements for build

Source: BloombergNEF

Appendix B. Data-center flexible capacity assumptions

Estimating the potential data-center flexible capacity required applying several steps. First was to estimate how much capacity of a particular flexible resource or technology across the data-center fleet (Table 18). This gives us the total flexible capacity present.

Table 18: Assumptions for the capacity of resource installed in a data center

			Colocation		Hyperscale	
			New build	Existing	New build	Existing
UPS		% MW per MW_{dc}	97%	99%	90%	99%
Load shifting	Time	% MW per MW_{dc}	100%	100%	100%	100%
	Location	% MW per MW_{dc}	100%	100%	100%	100%
Back-up gen	Diesel	% MW per MW_{dc}	70%	80%	50%	80%
	Gas	% MW per MW_{dc}	26%	19%	38%	18%
	H2	% MW per MW_{dc}	1%	0%	2%	1%
Back-up battery		% MW per MW_{dc}	3%	1%	10%	1%

Source: BloombergNEF. Note: MW_{dc} denotes the data-center capacity

Once we have the total installed capacity of each flexible resource, then we estimate how much of each resource's power is available for flexibility. For example, a UPS could delivery 100% of its rated power capacity for flexibility.

Table 19: The potential flexible resource power capacity assumptions

			Colocation		Hyperscale	
			New build	Existing	New build	Existing
UPS		MW_{flex} per MW_{dc}	1.00	1.00	1.00	1.00
Load shifting	Time	MW_{flex} per MW_{dc}	0.20	0.20	0.50	0.50
	Location	MW_{flex} per MW_{dc}	0.20	0.20	0.50	0.50
Backup gen	Diesel	MW_{flex} per MW_{dc}	1.00	1.00	1.00	1.00
	Gas	MW_{flex} per MW_{dc}	1.00	1.00	1.00	1.00
	H2	MW_{flex} per MW_{dc}	1.00	1.00	1.00	1.00
Backup battery		MW_{flex} per MW_{dc}	1.00	1.00	1.00	1.00

Source: BloombergNEF. Note: MW_{flex} denotes the flexible power capacity. MW_{dc} denotes the data-center capacity

Similar to the potential flexible power capacity, we estimated the resources flexible energy capacity. This is the duration, the numbers of hours, by the rated power capacity that a resource can provide.

Table 20: The potential flexible resource energy capacity assumptions

			Colocation		Hyperscale	
			New build	**Existing**	**New build**	**Existing**
UPS		MWh_{flex} per MW_{dc}	0.08	0.08	0.08	0.08
Load shifting	Time	MWh_{flex} per MW_{dc}	1.60	1.60	4.00	4.00
	Location	MWh_{flex} per MW_{dc}	1.60	1.60	4.00	4.00
Backup gen	Diesel	MWh_{flex} per MW_{dc}	2.00	2.00	2.00	2.00
	Gas	MWh_{flex} per MW_{dc}	8.00	8.00	8.00	8.00
	H2	MWh_{flex} per MW_{dc}	2.00	2.00	2.00	2.00
Backup battery		MWh_{flex} per MW_{dc}	2.00	2.00	2.00	2.00

Source: Note: MW_{flex} denotes the flexible energy capacity. MW_{dc} denotes the data-center capacity

Finally, after we have calculated the total potential flexibility data centers can provide, we estimated how many of the data centers are willing to provide that flexibility. This is the least technical of the methodology and has the greatest variability.

Table 21: The available flexible resource capacity assumptions

			Colocation		Hyperscale	
			New build	**Existing**	**New build**	**Existing**
UPS		MW_{flex} per MW_{dc}	0.30	0.20	0.50	0.40
Load shifting	Time	MW_{flex} per MW_{dc}	0.06	0.06	0.25	0.25
	Location	MW_{flex} per MW_{dc}	0.01	0.01	0.13	0.13
Backup gen	Diesel	MW_{flex} per MW_{dc}	0.02	0.02	0.02	0.02
	Gas	MW_{flex} per MW_{dc}	0.30	0.20	0.50	0.40
	H2	MW_{flex} per MW_{dc}	0.30	0.20	0.50	0.40
Backup battery		MW_{flex} per MW_{dc}	1.00	1.00	1.00	1.00

Source: BloombergNEF. Note: MW_{flex} denotes the flexible capacity. MW_{dc} denotes the data-center capacity

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