WHITE PAPER

FRENCH DATA CENTERS: UNLOCKING THE POTENTIAL OF FLEXIBILITY

GIMELEC

GIMELEC would like to thank Eaton & BloombergNEF for their kind permission to use their study "Data Centers and Decarbonization - Unlocking Flexibility in Europe's Data Centers" as a working basis.

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EDITORIAL

As a consequence of the explosion in digital usage, the number of data centers is growing rapidly worldwide. In France, projects are growing both in numbers and in size: power exceeding 100 MW is now the norm rather than the exception.

The data center sector is an electricity-intensive industry: energy bills account for an average of 20% of a data center's total expenses. Energy efficiency has therefore always been at the heart of data center strategy, as their competitiveness depends on it. Further their power consumption has often been overestimated in the public eye, driving an emphasis on efficiency to ward off public scrutiny.

Data center energy consumption has risen to level that is impactful on a grid planning and operations level. RTE, the french transmission system operator, whose energy scenarios serve as the basis for government planning, now explicitly considers them in its forward-looking work.

Their growing appetite for "electric power" comes on top of the global trend towards electrification of the existing industries, future reindustrialization and emerging sectors such as hydrogen. The transmission system operator has to meet these new needs while keeping costs under control for French consumers, who ultimately finance a substantial part of the development of electricity networks.

GIMELEC has long been convinced that a siloed approach from power grid producers and consumers leads to a dead end. Electrification, the backbone of the energy transition, requires system-level thinking, with flexibility as one of the levers for optimization.

The data center industry has several technology levers capable of creating different kind of flexibilities. It is thus uniquely positioned in the industrial world. But technology alone is not enough; the right economic and regulatory frameworks need to be defined, so that both costs and value creation can be equitably shared. Indeed, beyond data center operators, their customers also have an important role to play in the development of flexibility.

France has a head start when it comes to flexibility. If applied to the French data center sector, it could make it more acceptable, attractive and competitive. In the face of complexities, however realizing the potential of flexibility is by no means an easy task! It requires education and dialogue.

The aim of this white paper is to inform as many people as possible about the technological solutions available to data centers to develop their flexibility. It also addresses the regulatory, economic and contractual challenges to be met in order to transform data centers into flexibility levers for the benefit of data centers operators, their customers and network operators alike.

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UNLEASH THE POTENTIAL FOR FLEXIBILITY DATA CENTERS

ENERGY FLEXIBILITY: A NEW STAGE FOR DATA CENTERS

The growing number of data centers in France is the consequence of the proliferation of digital uses at all levels of society. In France, the IT capacity of data centers has risen from 235 MW in 2016 to 566 MW in 2022. This sharp rise is set to continue over the next few years. The report envisages two growth options: a "low" scenario extending past growth, which would bring capacity to 2,198 MW in 2035; a "high" scenario taking into account the latest trends, including the development of artificial intelligence, which would boost capacity to 5,182 MW in 2035.

The installation and operation of data centers creates new challenges. First and foremost, operators need access to land close to major urban centers. At the same time, they need to secure their site's connection to the power grid, often anticipating the need for additional capacity. RTE, the French electricity transmission system operator, is itself subject to major investment and balance-of-power management constraints, due to the changes brought by the energy transition (electrification of industry, new uses, deployment of renewable energies).

As a result, electricity consumption by data centers is set to grow: an average level of 31 TWh is estimated for 2035, i.e. almost three times SNCF's current consumption. As such, they have a responsibility in the electricity system, and their energy efficiency actions will be particularly important in controlling their impact.

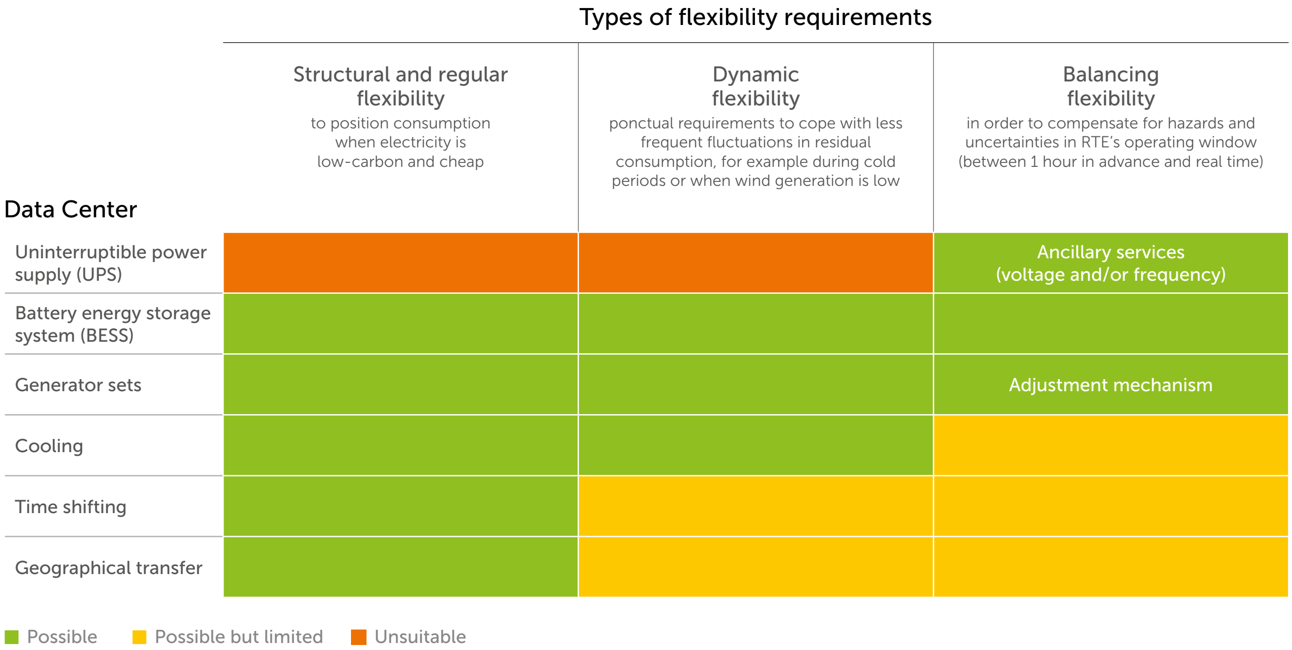
The large size of the sector will also offer an opportunity: data center operators could leverage flexibility. Flexibility offers many advantages: faster, cheaper grid connections, cheaper electricity, and less CO_2 emissions.
Further, flexibility offers the power grid an additional lever for resilience and investment optimization.

The technical means of data center flexibility are based first and foremost on the energy resources already available to their operators: non-interruptible power supplies (UPS) with batteries, generators and cooling systems. Complementary battery modules could also be envisaged, as well as more optimized controls via building management systems (BMS) or energy management systems (EMS). Finally, shifting IT tasks, either temporally or geographically, can contribute to modulating electricity needs.

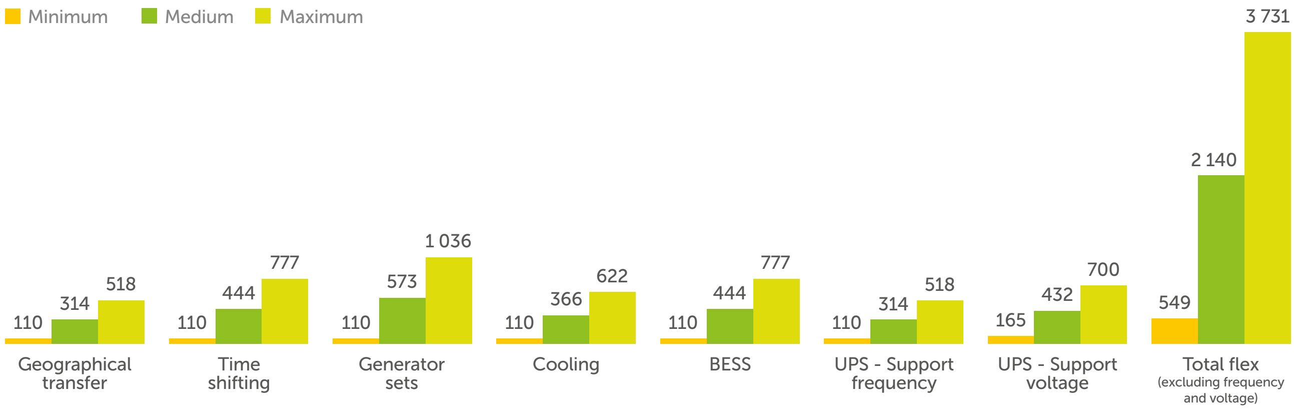
The level of flexibility that data centers could mobilize in France in 2035 is estimated at a minimum of 549 MW, and could theoretically exceed 3.7 GW if all solutions were implemented, depending also on the needs of the electricity transmission system operator.

Flexibility potential is fairly evenly distributed between the various levers, and allows several types of action to be envisaged: frequency and voltage ancillary system services; participation in the mechanism for grid power balancing; upward modulation of consumption during peaks in renewable electricity production; load shedding in the event of supply/demand imbalances.

OVERVIEW OF DIFFERENT FLEXIBILITIES AND TECHNOLOGIES



TOTAL FLEXIBILITY POTENTIAL FOR DATA CENTERS BY 2035 (MW)



Behind these theoretical figures lies the complex reality of data centers, whose primary mission is, and will remain, to ensure that the IT processes they host never come to a halt.
This potential also exists in a sector where customer service level agreements (SLAs) and data center operator requirements do not favor flexibility.
Deploying flexibility solutions in data centers therefore requires constructive dialogue between all stakeholders involved: data center operators and their customers, suppliers and services providers, grid operators, public authorities and electricity suppliers.

Some of the issues to be addressed are technical, such as the introduction of new technological building blocks like stationary battery storage or thermal storage. Others are regulatory, such as compliance with local standards for emissions of atmospheric pollutants, or the obligation for data centers to respond to calls from RTE.

Last but not least, the development of flexibility in data centers depends crucially on the evolution of contractual relations between all players in the value chain, in order to share responsibilities, risk, costs and benefits fairly.

PREAMBULE

GLOSSARY DATA CENTERS

DATA CENTER

According to the official European definition, "*a data center is defined as a structure or group of structures used to house, connect and operate computer systems/servers and related equipment for the storage, processing and/or distribution of data, as well as for related activities.*"

These buildings, which can range in size from a few m^2 to several tens of thousands of m^2, may belong to a company that operates them for its own IT needs, or they may be owned by 'colocation' providers – having built the data center for the purpose of leasing space to clients.

COLOCATION

Use of a data center built for the purpose of renting space for servers and other IT equipment to customers. Colocation data centers provide the building, cooling, power supply and bandwidth.

HYPERSCALE

Sometimes also referred to as "self-builds", these large-scale data centers are owned and operated by cloud service providers such as Amazon Web Services, Microsoft Azure and OVHCloud, or by technology companies such as Meta and Apple. Together with Google, they form the GAFAM group.

PRIVATE DATA CENTERS

Private data centers are generally owned by a single company for its own use, built on the site of the company's premises. While many companies have moved to the cloud (which relies on colocation and hyperscale data centers), banks, governments and healthcare companies still own a lot of private data center capacity.

RATED CAPACITY (MW OR GW)

The advertised capacity of a data center, i.e. generally the maximum capacity to which it has been authorized to draw by the grid operator. The actual electricity demand of data centers hardly ever corresponds to this rated capacity.

INSTALLED CAPACITY (MW OR GW)

Installed electrical capacity of an active, built data center. This figure takes into account the surface area of the data center actually built (which is less than the nominal capacity), the proportion of the built space that is rented (vacancy rate) and the proportion of the rented space structure that is filled by servers (called "Rack capacity")

This installed IT power, while not reflecting actual energy consumption, is important for our flexibility analysis, as data center back-up systems (such as uninterruptible power supplies, standby generators, etc.) are typically sized according to this parameter. This power also covers peripheral uses of energy, such as air conditioning and other IT equipment.

REAL COMPUTER POWER (MW OR GW)

This is the average power demand of a built and active data center (Live IT power). This value takes installed IT power and reduces it to reflect how many of its racks are in service (active rack capacity) and how many of them are in use (utilization rate).

UTILIZATION RATE (%)

The average utilization of servers installed in the data center, usually calculated on an annual basis. Utilization rates tend to be higher for hyperscale installations than for colocation data centers.

COMMISSIONING A DATA CENTER: THE PRINCIPLES

Depending on its size and the context of the project, the construction of a data center can take more than 5 years, from the drawing of the plans to commissioning. The better the operator plans its project, the more likely it is to meet commissioning deadlines, and to guarantee the sale of digital capacity at the right time. Large data centers are typically built and commissioned in phases.

Commissioning a data center involves a number of different partners. It varies according to the data center's planned activities, operators, location and country. Much of the initial process (land acquisition and permitting) is managed by a real estate company. These companies act either on behalf of a data center operator, or speculatively on the basis of expected data center demand.

1. ASSESSMENT, BUILDING PERMITS AND DESIGN

The developer of a new data center is usually a real estate company, which must first select a site and draw up a design plan, then obtain a building permit and an agreement for connection to the power grid. During this phase, a design capacity is announced for the site. This capacity is greater than that which will actually be built, but offers operators the possibility of future expansion.

The electricity grid operator undertakes to reserve this capacity for the data center operator. Permits for water, gas and internet connection must also be obtained. From initial application to construction of the first data center hall, it takes at least a year.

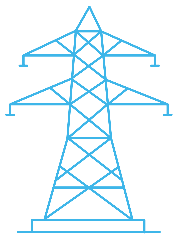
However, this first stage can take much longer if the electricity grid operator has to reinforce the grid to be able to connect the site. In France, delays are also lengthy, due to administrative procedures (building permits, possible delays for connection, ICPE files*), site start-up, construction site, constraints and equipment delivery times.

CONDITIONS FOR DATA CENTER CONNECTION BY RTE

In France, the transmission system operator RTE must examine all connection requests.
Those for data centers are added to those for other infrastructures. Current connection times are 2 to 3 years for HTB1 (63 or 90kV), 4 to 6 years for HBT2 (225 kV), and 6 to 9 years for HTB3 (400 kV).

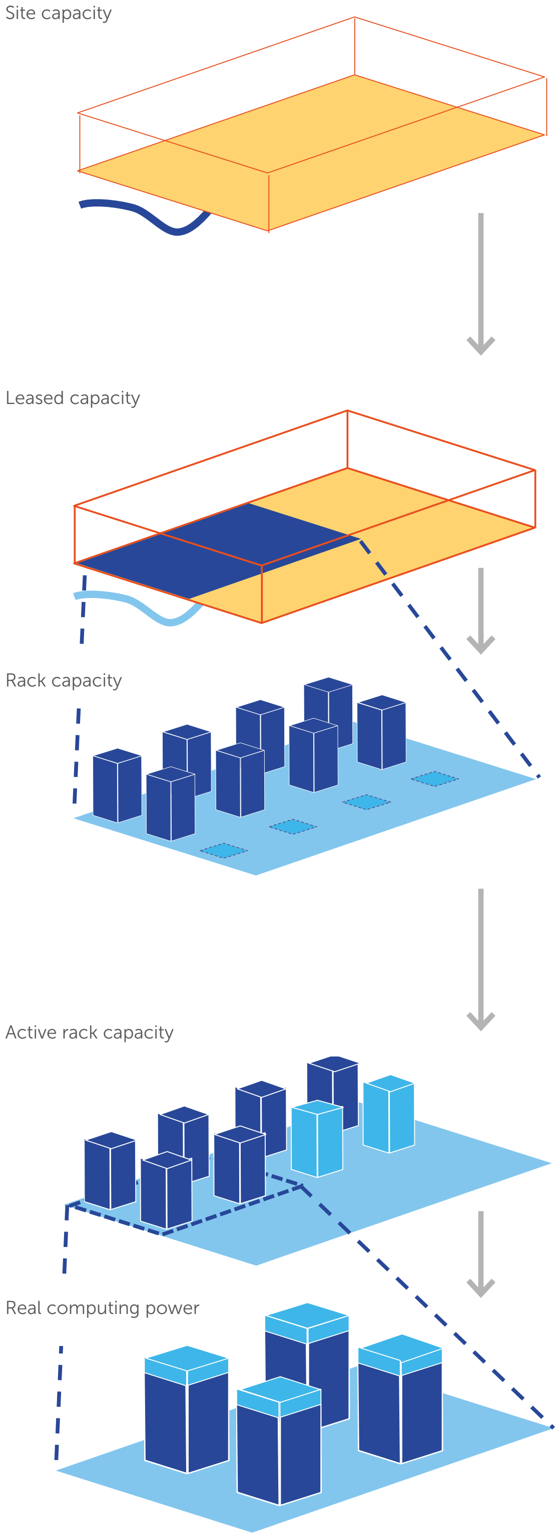
The authorization phase, which represents two-thirds of the project's time, must be anticipated and is carried out in collaboration between RTE and the project owner. Since 2016, 650 MW of requested connection capacity (Pracc) for data centers have been granted by RTE.

In addition, projects under development (connection contracts accepted) and projects under appraisal represent several thousand MW. The Ile-de-France region accounts for the vast majority of projects (80 to 90%).



* ICPE: Classified facility for environmental protection

DATA CENTER CAPACITY ASSESSMENT



Source: Bloomberg NEF

2. FIRST COMMISSIONING PHASE

Once the building permit has been approved, the next step is to construct the building shell. For large data centers, this "shell" may contain several data rooms.
For example, a 10 MW data center may comprise five rooms of 2 MW each. Commissioning a data room involves building the structure, installing flooring, lighting, cooling, security systems, UPS, backup power, etc., then installing the computer racks. Depending on the customer's requirements, the first phase of commissioning a data center may represent only a fraction of the total planned power: the increase in load varies according to the type of data center, the operator and the customers hosted.

3. SPACE RENTAL

For colocation operators, the next step is to lease space to customers. In markets with high IT demand, leases are signed even before the data center goes live, either because the customer wants to install the racks himself, or because the operator plans to install the racks before the customer actually needs them. When the space is leased, the servers are installed, then connected to the Internet and a power source.

The amount of leased space (see opposite) in which servers are installed is called "*racked capacity*", and the number of servers switched on and ready for use is called "*live rack capacity*".

4. INCREASING CAPACITY

Large operators tend to start building new data rooms, planning site expansions, or applying for planning permission for new sites when their existing spaces are 80% leased. It used to take two years for a large colocation site to reach 80% leasing. But in recent years, demand for cloud services has been so strong that it's common for new data centers to be fully leased before they're even completed. This has led to very rapid increases in data center capacity.

Previously limited to a maximum size of around ten MW, the largest current projects in France now exceed 200 MW.

1

DATA CENTERS IN EUROPE & FRANCE

1.1 EUROPE

Most of Europe's data center capacity is located in five countries: France, Germany, Ireland, the Netherlands and the UK. More specifically, this capacity is found almost entirely in five cities, known as FLAP-D markets: Frankfurt, London, Amsterdam, Paris and Dublin.

Markets outside France are the most important due to the presence of Internet "exchanges" and various other conditions favorable for large technology companies.
The size of these markets has historically been due to the availability of large tracts of land for construction, easy access to the power grid and its reliability, regulatory flexibility, attractive local taxation or a skilled workforce and demand for IT services.
The challenges facing Frankfurt, London, Amsterdam and Dublin in terms of flexibility were described in a 2021 report by Eaton, Statkraft and Bloomberg NEF[1].

In Europe, the average annual growth of the data center market has been 12% since 2016[2] driven by increased demand for IT services and the rapid migration of many business processes to cloud computing.
Whereas corporate IT infrastructure used to consist mainly of small, decentralized servers or servers in private data centers, much of today's computing is done in the cloud, hosted in hyperscale or colocation data centers.

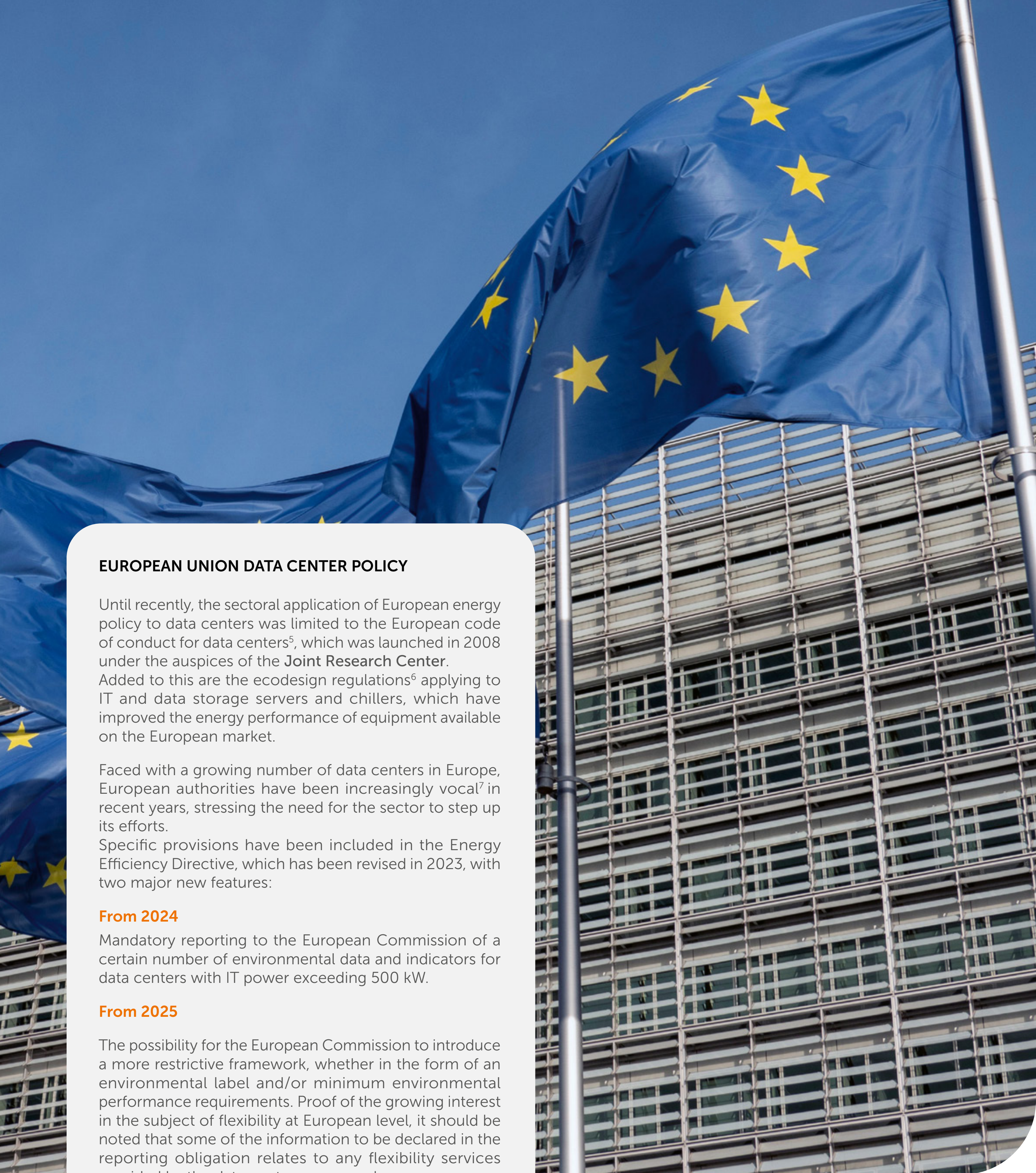
In its latest report[3] , the International Energy Agency (IEA) estimates that in 2022, there were around 1,240 data centers in Europe consuming almost 100 TWh, or 4% of European electricity consumption.
By 2026, the IEA expects this figure to rise to 150 TWh. Much of this increase comes from the development of 5G networks, the Internet of Things, new artificial intelligence applications and blockchains.

In addition, the European Union aims to reduce carbon emissions by at least 55% by 2030 compared to 1990 levels, and to achieve carbon neutrality by 2050. A number of initiatives support this ambition. The Green Deal was presented at the end of 2019 and has been supplemented by numerous other texts, such as the 2030 climate targets (September 2020), REPowerEU (March 2022), electricity market reform and the Net-Zero Industry Act (March 2023). In October 2023, the first phase of the border carbon adjustment mechanism also came into force, while the final texts of the Fit for 55 package were finalized.

In particular, the European framework aims to develop a strategy to improve the integration of the[4] energy system. This includes greater energy efficiency at all levels and the reduction of losses. For example, the recovery of waste heat from data centers to feed district heating networks is cited as a solution for an energy system based more on the circular economy. The development of electricity storage facilities and the elaboration of a network code on demand flexibility are also put forward.

The Clean Energy Package and the Electricity Market Directive also provide for various measures to improve the flexibility of the European electricity system.
These include the communication of real-time signals from wholesale electricity markets to consumers to encourage consumption modulation, the creation of markets for power system services, lowering of barriers to entry to these markets for decentralized energy sources, and the evolution of electricity and system services markets towards finer time granularity and greater frequency.

[1] *Data Centers and Decarbonization. Unlocking Flexibility in Europe's Data Centers, October 14, 2021.*
[2] *Source: Eaton, Statkraft, Bloomberg NEF, 2021.*
[3] *Electricity 2024, Analysis and forecast to 2026, available online at : https://www.iea.org/reports/electricity-2024.*
[4] *See the European Commission's July 2020 communication: https://eu r-lex.europa.eu/legal-content/FR/TXT/ PDF/?uri=CELEX:52020DC0299*



EUROPEAN UNION DATA CENTER POLICY

Until recently, the sectoral application of European energy policy to data centers was limited to the European code of conduct for data centers[5], which was launched in 2008 under the auspices of the **Joint Research Center**.
Added to this are the ecodesign regulations[6] applying to IT and data storage servers and chillers, which have improved the energy performance of equipment available on the European market.

Faced with a growing number of data centers in Europe, European authorities have been increasingly vocal[7] in recent years, stressing the need for the sector to step up its efforts.
Specific provisions have been included in the Energy Efficiency Directive, which has been revised in 2023, with two major new features:

From 2024

Mandatory reporting to the European Commission of a certain number of environmental data and indicators for data centers with IT power exceeding 500 kW.

From 2025

The possibility for the European Commission to introduce a more restrictive framework, whether in the form of an environmental label and/or minimum environmental performance requirements. Proof of the growing interest in the subject of flexibility at European level, it should be noted that some of the information to be declared in the reporting obligation relates to any flexibility services provided by the data center concerned.

In addition, the European Commission has commissioned a study which, among other things, addresses the data center as an integral part of its local energy infrastructure[8].

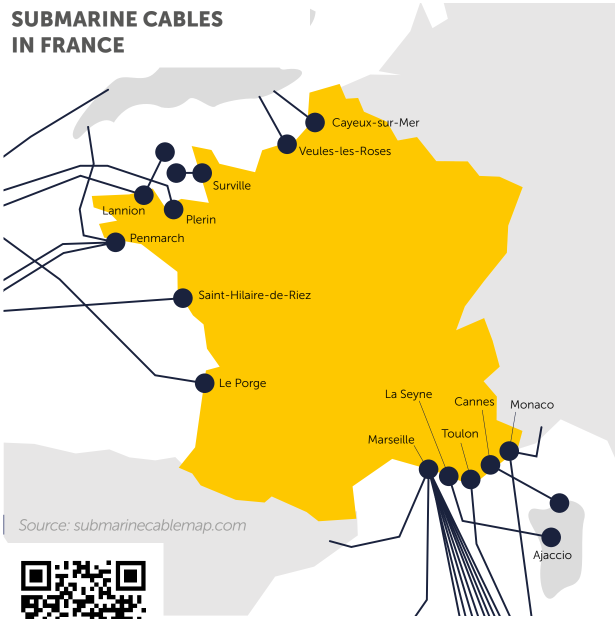
[5] https://e3p.jrc.ec.europa.eu/communities/data-centres-code-conduct
[6] https://eur-lex.europa.eu/EN/legal-content/summary/ecodesign-requirements-servers-and-data-storage-products.html
[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0552&qid=1666369684560
[8] https://www.borderstep.org/projekte/optimising-synergies-between-data-centres-and-energy-systems/
[9] https://www.francedatacenter.com/ressource/cartographie-des-adherents-france-datacenter-2023/

1.2 **FRANCE**

In France, the Paris region currently accounts for over 90% of installed data center capacity. However, France is unique in Europe in that it has a second major data center hub, located in Marseille.

Indeed, the city of Marseille is home to numerous fiber optic submarine cables serving Africa, the Middle East and Asia. In Bordeaux, a new submarine cable from the USA is also expected to boost local data center development.

SUBMARINE CABLES IN FRANCE



Source: submarinecablemap.com

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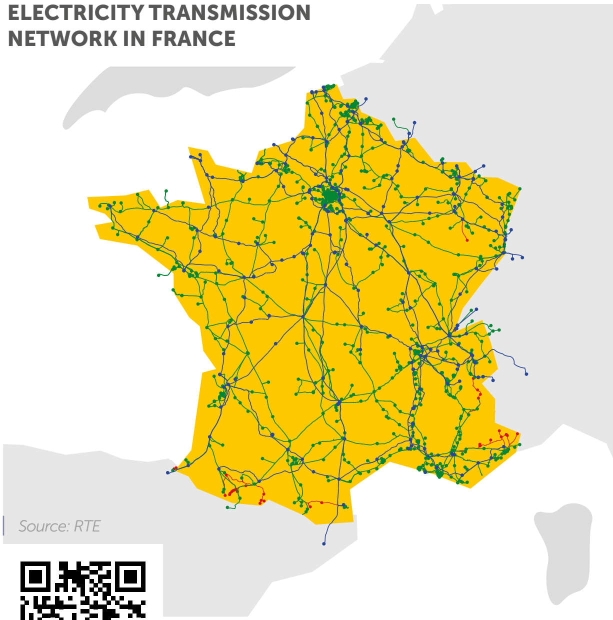
ELECTRICITY TRANSMISSION NETWORK IN FRANCE



Source: RTE

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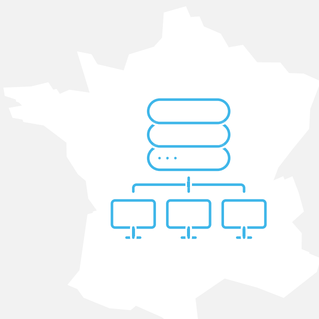
400 kV 225 kV 150 kV

DATA CENTER OPERATORS AND THEIR PARTNERS

According to the reference association France Datacenter[9], there are

250
commercial digital hosting centers (colocation) in France



5,000
hosted computer rooms and corporate data centers and administrations

Among the major hosting providers present nationwide and members of the association a r e Albian-IT, Atos, CyrusOne, Data4, Digital Realty, Eclairion, Equinix, Global Switch, Kyndryl, OVH (cloud operator) and Telehouse. Several regional hosting providers are also present: Advanced MedioMatrix, Blue, Caelis, Casino Immobilier, Euclyde, Etix Everywhere, FullSave, TDF and Thésée Datacenter.

In terms of energy performance, the Power Usage Effectiveness (PUE) indicator[10] is estimated to be 1.5 in France, in line with the world average (between 1.5 and 1.6). This figure reflects a relatively high-performance data center base in France, which still offers potential for energy savings in existing facilities. The latest-generation data centers commissioned since 2012 have a better index, below 1.4. ARCEP[11] also points out that the more powerful a data center, the lower its PUE (1.34 above 5 MW).

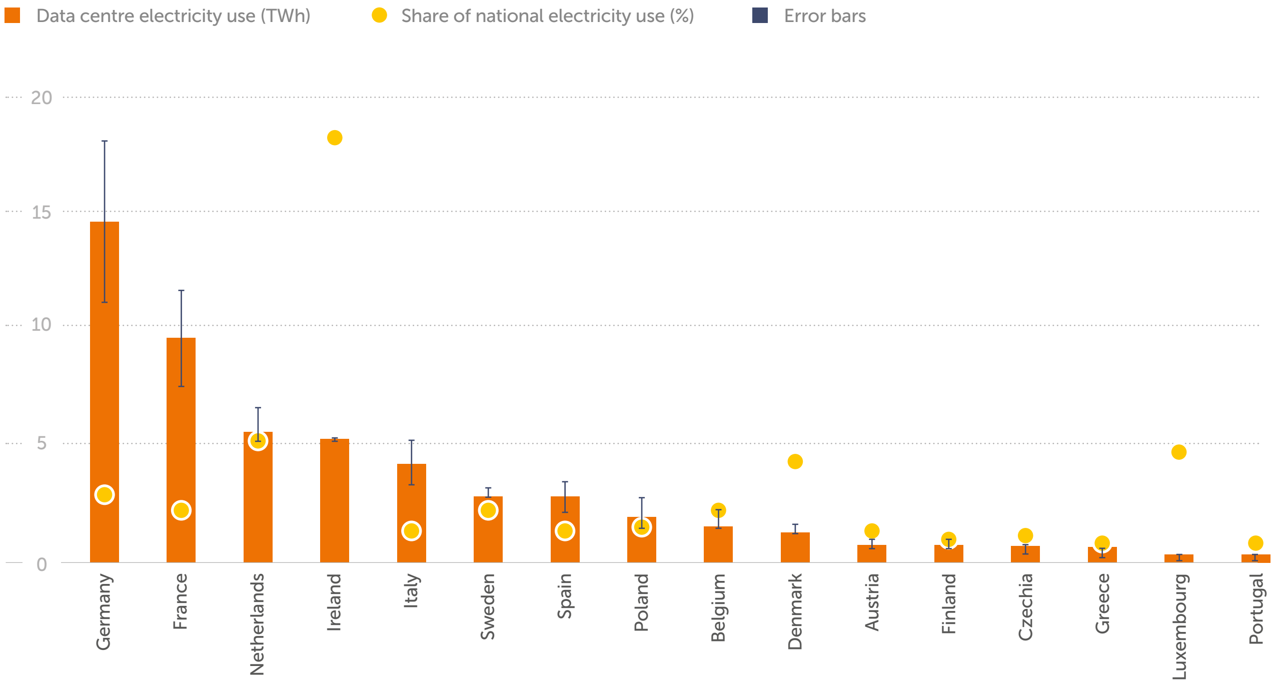
What's more, France's electricity production mix means that data center electricity supply is 95% decarbonized.

The proportion of electricity supply coming from renewable sources is estimated at 55%, as some sites sign direct contracts with renewable electricity producers.

The European Commission's Joint Research Center (JRC) estimates that French data centers account for 2.2% of national electricity consumption in 2022, or just under 10 TWh[12].

In France, annual growth has been more robust than on a European scale. It is estimated at 16% since 2016[13]. As a result, the available installed capacity of data centers in France is estimated at 566 MW in 2022, solely in colocation sites.

ESTIMATED DATA CENTRE ENERGY USE BY COUNTRY, 2022



Source: Joint Research Center (JRC)

[10] Source: Baromètre France Datacenter 2023, online at : https://assets.ey.com/content/dam/ey-sites/ey-com/fr_fr/topics/tmt/ey-barometre-france-data-center_20230908.pdf
[11] Assessment of the environmental impact of digital technology in France and outlook analysis, March 2023, available online at:https:/ / w w w . a r c e p.fr/fileadmin/user_upload/observatoire/enquete-pns/edition-2024/enquete-annuelle-pour-un-numerique-soutenable_edition2024.pdf
[12] Energy Consumption in Data Centres and Broadband Communication Networks in the EU, JRC,February 16, 2024, available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC135926
[13] Source: Baromètre France Datacenter 2023
[14] Assessment of the environmental impact of digital technology in France and outlook analysis, March 2023
[15] Bilan prévisionnel 2023-2035 de RTE, Part 2 on consumption, page 43 : https://www.rte-france.com/analyses-tendances-et-prospectives/les-bilans-previsionnels
[16] https://download.schneider-electric.com/files?p_Doc_Ref=SPD_WP110_EN&p_enDocType=White+Paper&p_File_Name=WP110_V2.1_EN.pdf

1.3 ENERGY OUTLOOK

The task of forecasting remains highly complex in a fast-growing sector, subject to numerous technological evolutions and a shifting geopolitical context. Energy forecasting in the sector since the 2000s is a good illustration of this, since energy consumption figures have systematically grossly overestimated reality.

An assessment carried out by ADEME and ARCEP[14] indicates a consumption of 12 TWh for all data centers in France in 2020, which would rise to 16 TWh in 2030 in a trend scenario, i.e. +33%.

If we consider only the commercial data centers that interest us here, their consumption is 5.6 TWh in 2020 and 13.4 TWh in 2030 in this study.

The assumptions made by ADEME and ARCEP are:

- more than double the surface area of these data centers (from 414,000 to 894,000 m^2);
- a load factor that rises from 50% to 55%;
- an average PUE ranging from 1.55 to 1.32.

Extending this trend would bring the electricity consumption of commercial data centers to 18-19 TWh by 2035.

In the reference scenario of its projected supply estimates, the french TSO RTE estimates that electricity consumption by data centers will be around 23-28 TWh in 2035[15] compared to overall national consumption of between 580 and 640 TWh.

RTE is considering other trajectories where electricity consumption in France would be lower, but these would have relatively little impact on data centers, whom demand could down to around 20 TWh.

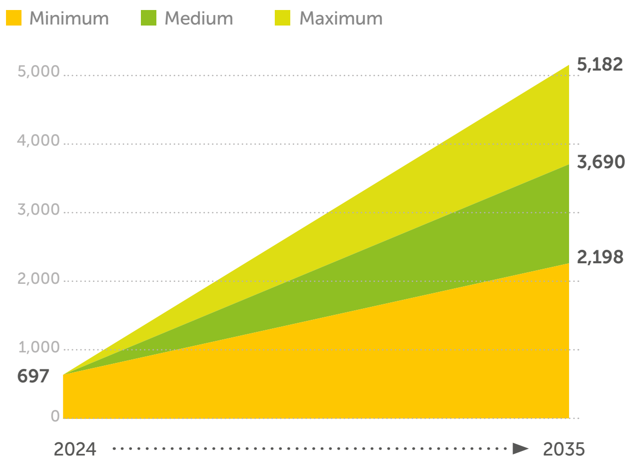
In 2022, the France Datacenter association estimated that the capacity of data centers in France would continue to grow at an average rate of 11% per year until 2033. Since then, the sector's growth has accelerated due to new needs linked to artificial intelligence.
In 2024, France Datacenter raised its growth forecast to between 13% and 14%.

In the remainder of this document, two assumptions are made for average growth between now and 2035:

- a low growth assumption of 11% per year, leading to a data center installed base of 2,198 MW in 2035;
- a high growth assumption of 20% per year, leading to a total installed capacity of 5,182 MW in 2035.

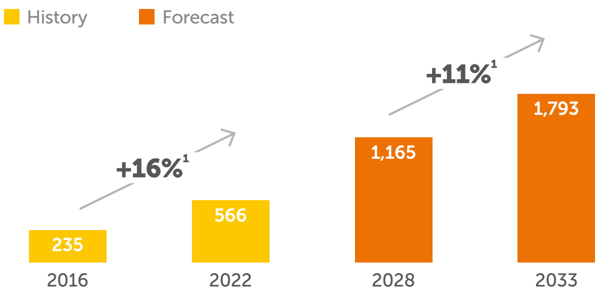
The sector is therefore expected to see its IT power increase by between 3 and 7.5 times between now and 2035:

IT POWER (MW)



Translated in terms of electricity consumption, and assuming an 80% utilization rate in 2035 and a PUE of 1.2, the sector would consume between 18.5 and 43.6 TWh. This very wide range reflects current uncertainties but, with an average of 31 TWh, is consistent with the values put forward by RTE.

TOTAL AVAILABLE DATA CENTER CAPACITY IN FRANCE (MW, 2016-2033)



¹ Annual growth
Source: Baromètre France Datacenter 2023

IA GROWTH

There's still a great deal of uncertainty surrounding the growth of data centers due to the rise of artificial intelligence (AI). On a global level, some players[16] are predicting growth of 10% a year over the next 5 years in the number of "classic" data centers against 25% to 33% for those required to meet the needs of AI.

2

FLEXIBILITY NEEDS OF THE FUTURE GRID

All the different scenarios for achieving the national goal of carbon neutrality by 2050 have one thing in common: a massive electrification of our society.

The share of electricity in the global energy mix is set to rise from 20% in 2020 to 49% in 2050. France, for its part, is set to increase its share from 27% to 55%, according to the Stratégie Nationale Bas Carbone (SNBC).

From an operational point of view, this translates into a massive increase in low-carbon electricity generation, particularly renewable (see table), and very significant gains in energy efficiency. Finally, we need to consume at the right time.

ELECTRIC RESOURCES CAPACITY AND PRODUCTION IN RTE'S REFERENCE SCENARIO FOR 2035

2022	Hydropower	Solar	Onshore wind	Offshore wind	Nuclear
Capacity (GW)	25.8	15.7	20.6	0.5	61
Generation (TWh)	50	18.6	38.1	0.7	279*
2035					
Capacity (GW)	27-28	65-90	39	15-18	60-63
Generation (TWh)	60	80-110	85	50-65	360-370

**The 2022 deliverable from the nuclear fleet was affected by generic stress corrosion problems and maintenance delays. The 2019 deliverable, more in line with the normal state of the fleet (before Covid), was 380 TWh.*

Despite essential efforts to control consumption in terms of energy efficiency & sufficiency, the French energy model is set to steadily increase its electricity consumption, with new challenges to meet.

2.1 BALANCING SUPPLY AND DEMAND

The Commission de Régulation de l'Énergie (CRE) has set the French public electricity transmission system operator RTE[17] the following tasks:

- ensure balance between electricity production and consumption at all times;
- resolve congestion on the transmission network.

To this end, RTE builds up and activates balancing reserves supplied by balancing players: producers, consumers and other players likely to inject or withdraw energy from the grid.

RTE has three types of reserves - primary, secondary and tertiary - to absorb imbalances between electricity production and consumption. In addition, "voltage system services" enable RTE to control voltage on the transmission network.

AUTOMATICALLY ACTIVATED PRIMARY AND SECONDARY RESERVES

When production is lower than consumption, the generating units slow down and the network frequency drops from its reference value of 50 Hz. When production exceeds consumption, generating units speed up and frequency increases.

The primary and secondary reserves (known as "frequency system services") are activated automatically to contain the frequency deviation, restore the frequency to 50 Hz and bring border energy exchanges back to their scheduled value. The primary reserve, activated in a decentralized way at the level of each generating unit, is activated in 15 to 30 seconds; the secondary reserve, activated automatically by RTE, in 400 seconds.

CONSUMER SITES CAN CONTRIBUTE TO VOLTAGE REGULATION

To guarantee the safe operation of the power system, RTE is responsible for voltage regulation on the public transmission network (PTR), in a context of ever-increasing constraints:

- in high voltage, in the short and medium term, due in particular to the undergrounding of electrical networks, and the development of loads (consumption) with increasingly capacitive electrical characteristics (i.e. injecting reactive power);
- in the longer term, with the arrival of large numbers of high-consumption customers.

Over the next few years, in areas where the PTR is under strain, RTE plans to increase the number of voltage control points using consumer technologies that enable dynamic, continuous voltage control.

This innovative service, whose current technical and financial terms are described in the rules for voltage system services, requires a contract with RTE, and is remunerated[18].

[17] https://www.cre.fr/electricite/reseaux-delectricite/services-systeme-et-mecanisme-dajustement.html
[18] https://www.services-rte.com/%20/fr/actualites/r%C3%A9glage-de-la-tension-dans-des-zones-en-contrainte-par-un-site-consommateur.html

TERTIARY RESERVE OR BALANCING MECHANISM

Unlike the primary and secondary reserves, the tertiary reserve is activated manually by an RTE dispatcher through the balancing mechanism. It is used to supplement the secondary reserve if the latter is depleted or insufficient to cope with an imbalance, but also to replace the primary and secondary reserves or anticipate a future imbalance.

Tertiary reserve can also be used to resolve constraints on the transmission system resulting from an excess or shortage of local generation.

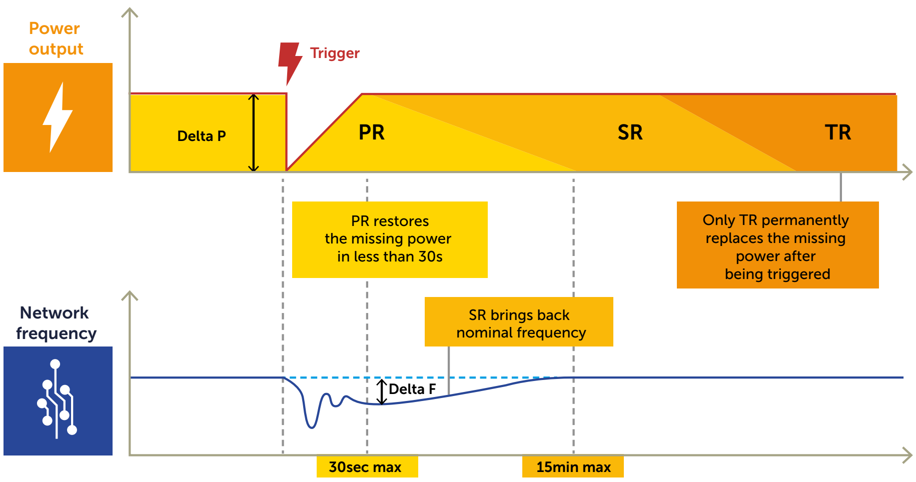
In accordance with article L. 321-13 of the French Energy Code, all producers connected to the transmission system are obliged to offer their available power to RTE.

In addition, French consumers and foreign players can, on a voluntary basis, make offers on the French balancing mechanism.

In addition, RTE ensures that it has sufficient tertiary reserves by concluding contracts with balancing players, in advance of real time, to ensure the availability of reserve resources. These players must submit bids on the balancing mechanism, in exchange for payment of a fixed premium. A distinction is made between rapid reserves (which can be mobilized in less than 13 minutes) and complementary reserves (which can be mobilized in less than 30 minutes).

OPERATION OF RESERVES TO RESTORE PRODUCTION/ CONSUMPTION BALANCE

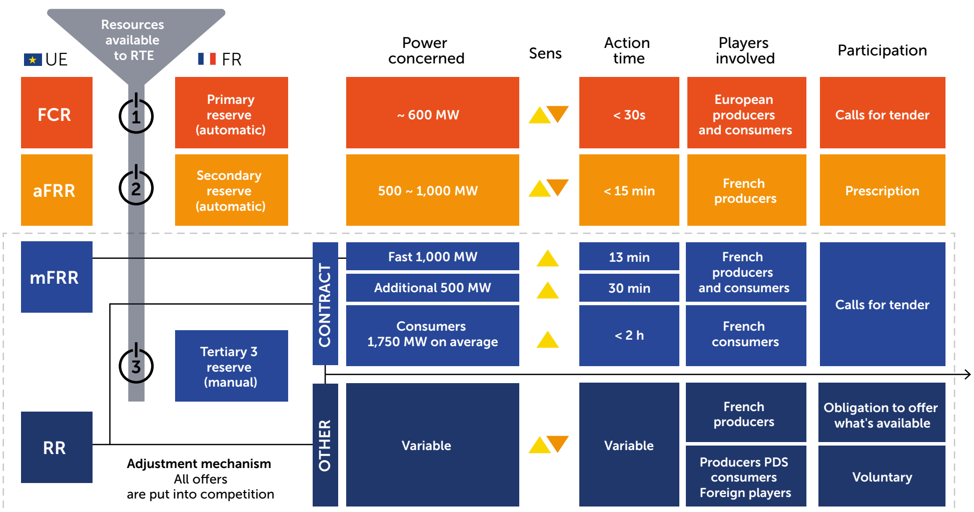
PR : Primary Reserve
SR : Secondary Reserve
TR : Tertiary Reserve



Source: CRE

FEATURES DIFFERENT RESERVE SYSTEMS

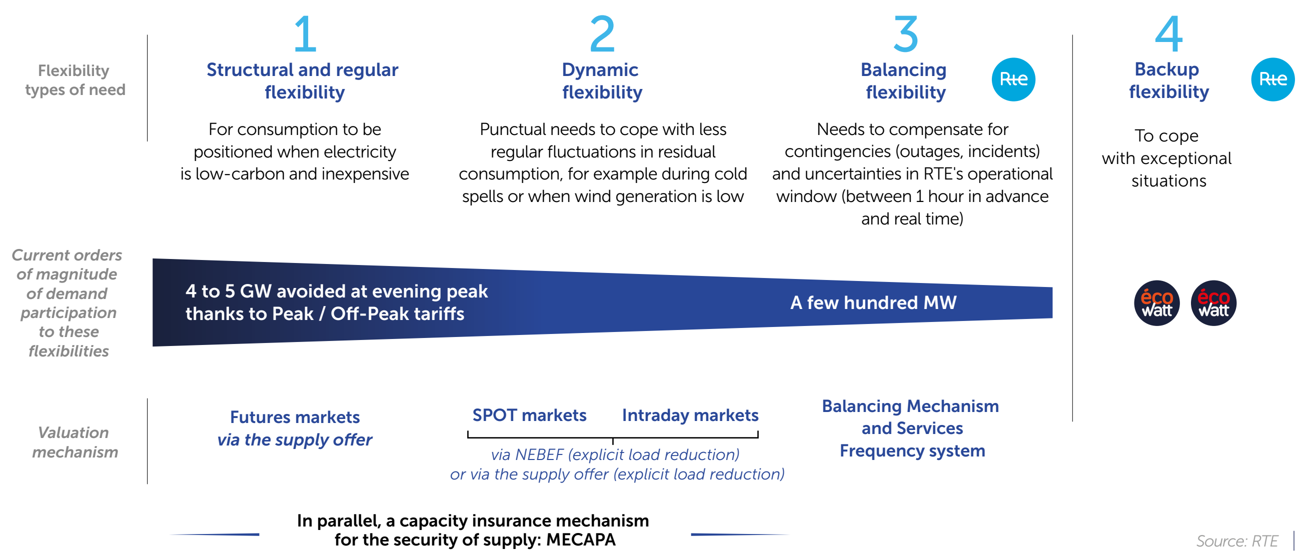
▲ Upward activation
▼ Downward activation



Source: CRE

According to RTE, four levels of flexibility can be distinguished, and this segmentation must be taken into account when considering possible, or even desirable, developments. The main need is for structural and regular flexibilities to ensure that consumption is in phase with periods of low-cost, decarbonized generation. At the other end of the spectrum, back-up flexibilities aim to overcome exceptional situations. In between, dynamic and balancing flexibilities are used to offset fluctuations in the balance of the power system.

DIFFERENTIATED LEVELS OF FLEXIBILITY



Source: RTE

2.2 OPTIMIZING THE GRID TECHNICALLY & ECONOMICALLY

According to the CRE[19], "*in response to the need for decarbonization and energy transition, the public authorities have launched a proactive plan aimed at electrification and reindustrializing France. This plan reinforces the need to develop sufficient electricity network infrastructures to accommodate new installations. Because of the growing demand for new connections, and to ensure efficient processing of these requests in terms of lead times and costs, it is necessary to optimize the use of public electricity network capacity. Tariffs for the use of public electricity networks (TURPE) play a key role in network development, notably by covering a significant proportion of consumer connection costs (all network reinforcement costs are covered by TURPE, as well as 30% of network extension costs for connections to the transmission network, and 40% of extension and connection costs for connections to the distribution network). In return for this financial support from the local authority, users are expected to optimize their connection power according to their real needs.*"

By 2040

At this stage, Enedis and RTE are planning to invest

200 billion euros

in the French power grid.

This is an extremely large amount, largely borne by all consumers, which alone illustrates the absolute necessity of optimizing and spreading it over time to guarantee the acceptability of electrification and digitalization.

[19] https://www.cre.fr/documents/consultations-publiques/conditions-de-modification-par-les-gestionnaires-de-reseau-public-de-la-puissance-de-raccordement-electrique-des-utilisateurs-en-application-de-larticle-l-342-24-du-code-de-lenergie.html

2.3 **COST-EFFECTIVE CONSUMPTION**

As renewable energies develop and take the place of controllable thermal generation, the need for flexibility increases in the above-mentioned areas.

Electricity supply and demand must be in balance at all times. Trading on wholesale electricity markets is the primary means of ensuring this, with generators, traders and suppliers adjusting their positions both in advance and throughout the day. Fundamentally, as wind and solar increase, there will be greater variability in the "residual load", i.e. the demand to be met after wind and solar contributions have been deducted.

This will manifest itself in periods when these two renewable sources meet all (or almost all) demand and other periods when they provide only a small share of electricity. There will also be periods when the system rapidly switches from one to the other.

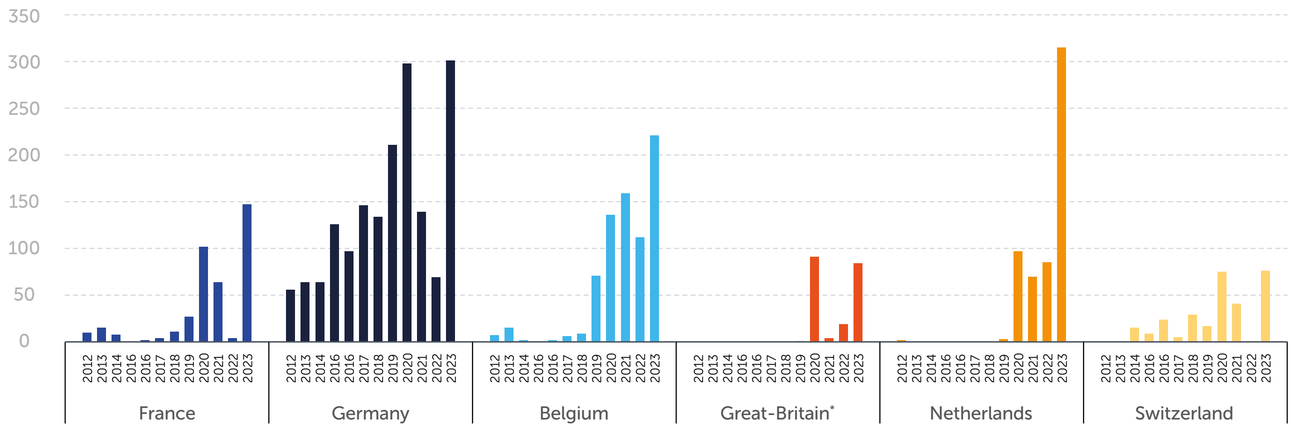
This means that all other resources - controllable generation, energy storage and demand flexibility - will have to adjust accordingly.

Recourse to these new means of integrating renewable energies is all the more important as the electricity market is experiencing increasingly regular episodes of negative electricity prices.

RTE specifies that:

> “the sharp rise in the share of renewable energies has had a visible impact on prices, generating a record number of hours characterized by negative prices on wholesale markets, a number which more than tripled compared to previous years, reaching **316 hours in 2023.**”

NUMBER OF HOURS WHEN ELECTRICITY PRICES WERE NEGATIVE, BY COUNTRY AND YEAR



** Great Britain and Northern Ireland do not belong to the same market area: the data displayed here only concern Great Britain and not the United Kingdom.*

Source: EPEX

Depending on the contract they have with their energy supplier, "flexible" consumers may therefore have a major economic advantage in shifting their consumption to the middle of the day, when renewable energy production lowers electricity prices, as early as the end of winter.

3

SOURCES OF DATA CENTER FLEXIBILITY

At present, flexibility services are provided mainly by hydroelectric dams, industry and fossil fuel power plants, the latter of which are due to shut down in the very near future.
New sources of flexibility are joining or will soon join them: stationary battery storage systems, electric vehicle batteries, electrolytic hydrogen production centers, housing and tertiary buildings, and data centers.

The primary purpose of a data center's energy infrastructure is, and always will be, to ensure the continuity of digital services. To date, data centers are a largely unknown source of flexibility, as they are themselves sophisticated energy systems. However, they can be part of a more open, interactive and flexible electricity system, with a number of benefits in store.
In this context, data centers could be a major source of flexibility because they:

- represent a significant power demand that can, in part, be shifted depending on grid conditions;
- concentrate high power consumption in a single location, which is easier to mobilize than the numerous small powers distributed throughout homes and electric vehicles;
- host a wide range of flexible on-site energy resources;
- already have sophisticated monitoring, control, communication and automation systems, unlike other activities or homes.

For a data center to meet electrical flexibility requirements, several criteria must be met:

- the advance notice it needs to respond to a flexibility signal;
- ramp rate, i.e . the time required to reach maximum capacity;
- the duration of the flexible response.

3.1 UNINTERRUPTIBLE POWER SUPPLY

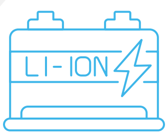
An Uninterruptible Power System (UPS) is an electrical system consisting of an inverter coupled to stationary batteries, which provides an instant, seamless transition to backup power during a disruption or failure of the electrical grid, for a limited period of time.

Data centers are the main users of these systems, which also improve power quality during normal operation. UPS systems are generally designed to provide emergency power for 5 to 15 minutes, until another source of emergency power, such as a generator, is activated (see chapter 3.3).
It is therefore technically possible for a UPS to provide flexibility services to the power grid by mobilizing the energy stored in its batteries. By its very nature, a UPS can deliver high power very quickly, but for a limited duration, which corresponds to the provision of system services to the power grid, such as frequency response (see chapter 2.1).
The power available and its duration depend on the type of batteries installed, their size and the level of safety margin required by the operator to maintain the UPS's primary function.

UPS BATTERY TYPES

Historically, UPS systems have been based on lead-acid batteries. In recent years, lithium-ion technology has been gaining ground, thanks to lower costs, higher energy density and longer service life. Currently equipping 30% of the installed base of UPS systems, lithium-ion batteries should account for 80% by 2035. However, these estimates must be treated with caution, as the battery sector benefits from numerous technological innovations, its market is subject to highly variable supply-demand balances, and the UPS model considered by a data center may be satisfied with lead-acid technology.

Generally speaking, lead-acid batteries are sensitive to charge-discharge cycles, and will be reserved for frequency support services: this is the case in some northern European countries, for example, with around ten discharges per year lasting less than a second. Lithium-ion technology, on the other hand, makes it possible to envisage longer charge-discharge cycles: depending on the design, discharge times of 15 minutes can be envisaged, or charge times to absorb a peak in renewable energy production, for example.



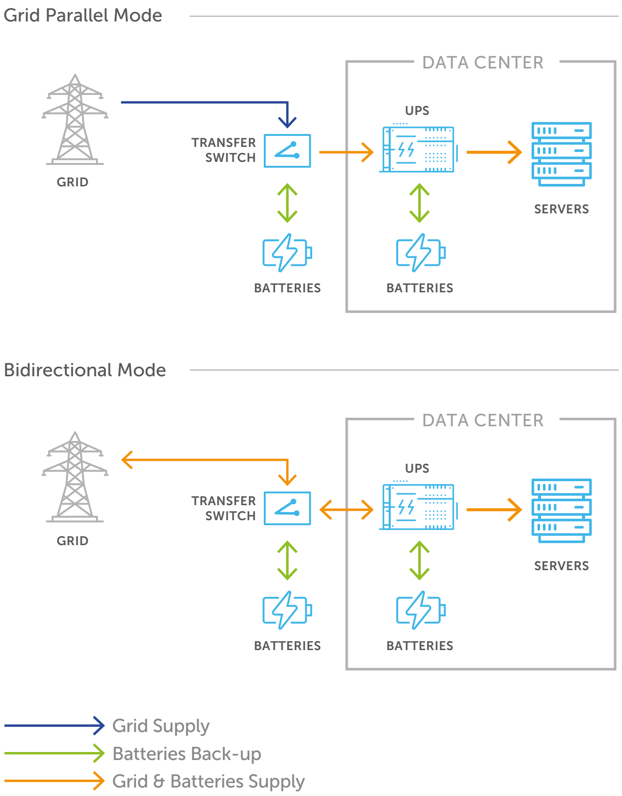
3.2 BATTERY ENERGY STORAGE SYSTEMS

Another source of flexibility could be the addition of Battery Energy Storage Systems (BESS) with a much longer duration (several hours) than that associated with UPS (5 to 15 minutes).

This BESS would rely heavily on the electrical infrastructure of the UPS backup system.

This type of installation is not necessarily intended to replace an existing backup system such as a generator, but to optimize the electricity supply according to the time of day.

BESS PRINCIPLES



Source: ENGIE

3.3 GENERATOR SETS

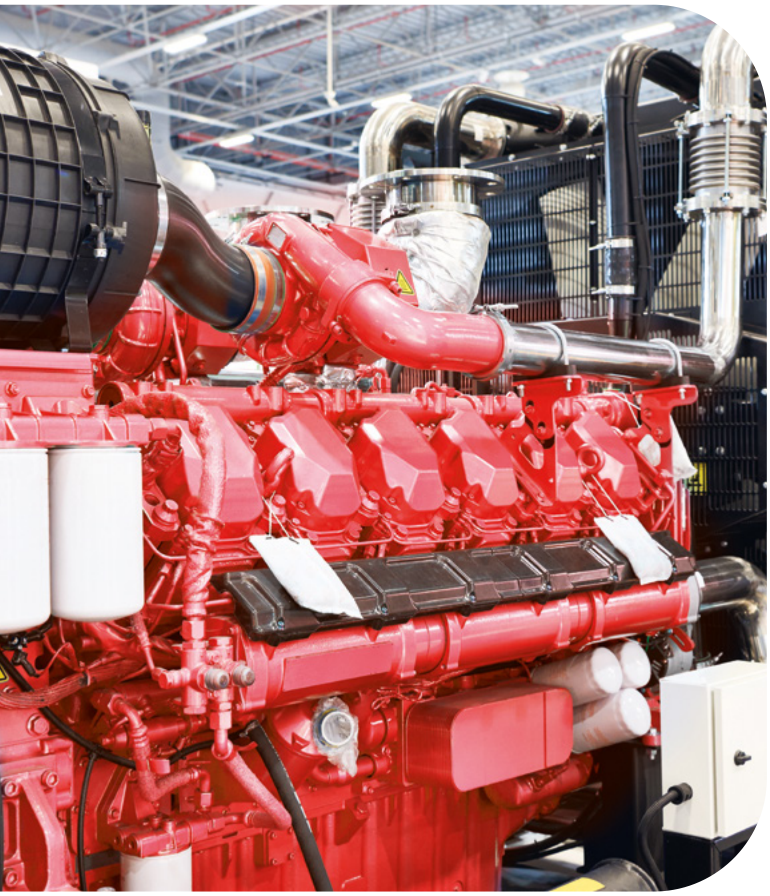
To ensure business continuity in the event of a power cut, almost all data centers in France are equipped with generators.

In the event of a power failure, a generator starts up within seconds, quickly reaches nominal operation and takes over from the UPS (see section 3.1) within minutes.

A genset can technically operate for several days: each data center is equipped with fuel storage tanks allowing autonomy of up to 72 hours, to compensate for any fuel delivery problems over a long weekend, for example.

The time scale of services that can technically be provided by a generator therefore ranges from a minute to several days.

Almost all the generators installed in France today serve as "insurance" in the event of incidents on the power grid, which are rare occurrences. They therefore only run for a handful of hours a year to check their operability, and therefore have a limited carbon footprint.



NEW REQUIREMENTS FOR GENERATORS

Faced with the tensions on electricity supplies that emerged during the winter of 2022/2023 in France, the government decided to oblige certain categories of generator to participate in balancing the French power grid: a 2022 law, still enforced thus requires "*consumption sites are equipped with power generation or storage facilities of more than 1 MW in order to provide them with back-up power to make available to RTE, via the balancing mechanism, all of their unused and technically available power.*"

This provision is based on provisional exemptions, particularly in terms of environmental protection, since the generators installed in data centers today use fossil fuels without being equipped with after-treatment systems. These flue gas treatment systems are optional when the unit is only used as a back-up.

In addition, biofuels compatible with the installed base of gensets are now available. According to ADEME's carbon base[20] , these biofuels offer an emission factor of between 16 and 21 kgCO_2e / GJ PCI, compared with 75 for diesel.

These "used oil" products are compatible with the definition of renewable energy in the Renewable Energy Directive.

OTHER FUEL SOLUTIONS FOR GENERATOR SETS

Hydrogen-based backup solutions are also available, and numerous experiments have already been carried out, notably in the USA. However, it is unlikely that these solutions will be deployed in the short term, as they can only offer short-term autonomy. Indeed, for an equivalent level of service, e.g. 72 hours of autonomy, the quantity of hydrogen to be stored would pose serious security concerns especially in urban areas where data centers often are.

Finally, there are gas-fired solutions.

[20] https://prod-basecarbonesolo.ademe-dri.fr/documentation/UPLOAD_DOC_FR/index.htm?liquides2.htm

40%

of a data center's electricity consumption is devoted to cooling needs

3.4 COOLING SYSTEMS

As the International Energy Agency points out in its Electricity 2024 report, 40% of a data center's electricity consumption is due to its cooling needs.

The operation of computer racks generates heat, and to maintain the optimum temperature of electronic circuits, computer rooms must be cooled.
This average figure of 40% conceals a very heterogeneous reality: the proportion of cooling can be much higher in the oldest data centers, while it can be as low as 10% in the most recent and most performant ones; it also varies considerably according to the season and outdoor temperature levels.

In France today, almost all data centers rely on[21] chillers and chilled water loops to cool their rooms.
Most new or recent data centers also make use of free-cooling[22], with chillers only used when the outside air is too hot, usually in summer.
The quest for energy efficiency tends to favor free- cooling whenever possible, as it consumes very little electricity.

Chilled water systems offer a great deal of flexibility. An ice or phase-change material (PCM) storage system can be added to take over cold distribution for a period ranging from a few minutes to a few hours, depending on the system's design. This saves electricity consumption by the chillers.

It should be noted that the time required to fill the ice or PCM reserve is fairly long (several hours), and relies on different chiller operating modes from those used to cool computer rooms (-1°C/-5°C type regime), with the result that energy performance can be degraded. On the other hand, once stored, and if not used, the cold keeps very well (less than 2% loss per week). Storage also takes up more space than a "conventional" system.

Cold storage is already quite widespread in French overseas departments and territories, and in certain tertiary buildings in mainland France, such as hospitals. One example is the Centre National d'Études Spatiales (French national space research center), one of whose sites has supplemented its three cold production units (3 MW each) with 11 MWh of ice storage, providing just over an hour's autonomy.

In the data center sector, one site in northern France has 600 kW of ice storage to last 30 minutes. Another, with a capacity of 8 MW, has an ice storage capacity of 4 hours.

Finally, it's worth pointing out that the flexibility offered by cooling will be largely seasonal, thanks to free-cooling, the chillers running little or not at all during the winter and mid-season.

A LIQUID COOLING OPTION FOR AI?

Part of the Artificial Intelligence business will involve liquid cooling.
Several solutions are being developed (direct-to- chip, immersion[23]) to cool computer racks in this way, particularly those that will use high-density computing electronic components for AI or machine-learning.
The advantages of liquid cooling are numerous: much greater heat capacity, lower pump consumption, possibility of recovering waste heat, less noise, ease of maintenance and rack operating temperature up to 30-45°C.
In theory, this last point allows much greater use of free-cooling.

Nevertheless, the development of liquid cooling is likely to be limited to a minority share of the data center park over the next ten years.

[21] chillers: thermodynamic, air-conditioning-type machines that generate frigories either to cool air blown directly into computer rooms (direct expansion system), or to cool a water network circulating in the rooms (chilled water system). These systems consume electricity to compress and evaporate the refrigerants;
[22] Free-cooling principle: outside air is captured to cool computer rooms, either directly or via an intermediate fluid (water or air).
[23] See, for example, this article in Techniques de l'ingénieur: https://www.techniques-ingenieur.fr/actualite/articles/severine-hanauer-le-immersion-cooling-is-a-promising-technology-for-datacenters-129874/
[24] Eaton, Statkraft, Bloomberg NEF, 2021

3.5 REGULATION & CONTROL

Like any industrial site, a data center accumulates several levels of energy consumption (in computer rooms, offices, technical rooms, etc.) which are used for different purposes: data storage and processing, computing, air conditioning, ventilation, secure power supply, heating, domestic hot water production, lighting, IT equipment, presence detection, security, telephony, internet connection, etc.

To operate these different levels in the best possible way, a regulation & control system is required:

- detailed monitoring of consumption;
- assign usage setpoints (temperature setpoint, activation times, airflow or lighting changes according to occupant presence, etc.);
- identify possible problems (device failure, leaks, etc.);
- predictive maintenance.

Control systems offer significant potential for energy savings, but also for flexibility.

They are essential in order to:

- comply with the lead and trigger times inherent in flexibility markets;
- automate the startup and shutdown of technology bricks that will provide flexibility services;
- optimize the use of different sources of flexibility.

**BACS DECREE:
DATA CENTERS CONCERNED**

As of April 8, 2024 (building permit submission date), the BACS (Building Automation and Control Systems) decree applies to tertiary buildings with air-conditioning or heating equipment rated at over 70 kW, whether or not combined with a ventilation system.

At this stage, France considers a data center to be a tertiary building, so this regulation apply to data centers as well.

3.6 TIME SHIFTING

Data centers are used for a whole range of computing tasks. Some take place in real time, such as video calls or financial transactions. Others are so-called "delay-tolerant" and don't need to be executed immediately, such as data backup or training for AI.

In a data center, the proportion between real-time operations and operations that can be time-shifted varies according to the data center user, the service required and the time of day. There is little data available on the proportion between these types of computational tasks; academic studies indicate that 30-50% of operations could be time-tolerant[24]. The future evolution of these proportions is still poorly understood, in view of the rise of the Internet of Things and AI. For the time being, it is assumed that these proportions will remain constant, and also that the evolution of computing tasks will be directly proportional to the evolution of data center energy demand. In reality, this proportion can vary from one data center to another, depending on its design, efficiency and customers.

Data center customers already schedule delay-tolerant tasks to manage data center computing capacity and maximize utilization and efficiency. The ability to delay a task therefore depends on the customer's willingness, the estimated time to complete it, and the time at which the user wants the task to be finished. If all the signals are positive, then the decision can be made to schedule the task.

Data center operators and users need a lead time of around 24 hours to schedule tasks. Interrupting and rescheduling a job at short notice is possible, but is currently the exception rather than the rule.

3.7 GEOGRAPHICAL TRANSFER

The ability to move the location of an IT task is not a new idea. Data center operators with multiple sites can already transfer jobs to optimize the efficiency and utilization of their data center estate, or to take advantage of lower energy prices in specific locations.

The possibility of moving the load exists if computing capacity is available and if the destination site has the appropriate hardware and software for data transfer. This is because transferring data from one site to another requires energy, which the data center operator must take into account when assessing the cost and impact in terms of carbon emissions.

The amount of load that can be shifted is difficult to quantify and depends on the user and the data center operator. Although there is little data to draw on, it is assumed that the same proportion of load can be moved as for a time shift by 2030. Similarly, it is estimated that information will be moved back to the originating data center within eight hours of the initial transfer. As with time-shifting, the data center operator wants visibility: what load is to be transferred, to where and in response to which signals.
This again limits the application of this solution to energy market exchanges, rather than system services.

The geographical transfer of the load probably involves moving the task to a more suitable location away from the user, which would increase the latency of the task. It depends on the task, but Microsoft research has shown that moving within Europe increases the latency experienced by the user during a video call by 10%, which Microsoft deemed negligible. Transferring calculations over the network takes time and can add to latency.

Combination of solutions

It's conceivable for a data center to install a back-up battery, which has a shorter operating time than a conventional diesel generator.
In tense moments when site reliability needs to be guaranteed, it could use it as an energy source, for the time it takes to geographically relocate computer calculations to another data center, thus ensuring continuity of service.

OVERVIEW OF DIFFERENT FLEXIBILITIES AND TECHNOLOGIES

Data Center	Types of flexibility requirements: Structural and regular flexibility (to position consumption when electricity is low-carbon and cheap)	Dynamic flexibility (ponctual requirements to cope with less frequent fluctuations in residual consumption, for example during cold periods or when wind generation is low)	Balancing flexibility (in order to compensate for hazards and uncertainties in RTE's operating window (between 1 hour in advance and real time))
Uninterruptible power supply (UPS)	Unsuitable	Unsuitable	Ancillary services (voltage and/or frequency) [Possible]
Battery energy storage system (BESS)	Possible	Possible	Possible
Generator sets	Possible	Possible	Adjustment mechanism [Possible]
Cooling	Possible	Possible	Possible but limited
Time shifting	Possible	Possible but limited	Possible but limited
Geographical transfer	Possible	Possible but limited	Possible but limited

■ Possible ■ Possible but limited ■ Unsuitable

3.8 FLEXIBILITY POTENTIAL AVAILABLE IN DATA CENTERS IN 2035

Three factors must be taken into account to estimate the flexibility potential of data centers in 2035:

1
the installed capacity of flexibility resources, the number of data centers equipped with them, and their power

2
the capacity of each resource to be technically available to serve the power system without affecting operations data centers

3
the proportion of data center operators willing to participate to flexibility services

The second and third points can be deduced from the installed capacity: first by determining the existing capacity potential, then the quantity that could actually be available, given that data center operators' willingness to participate in flexibility will not be 100%.

On the basis of our analyses and discussions with various stakeholders, we can conclude that the maturity of the subject of flexibility varies from one structure to another, but overall remains far from operational implementation.

At this stage, the sector's maturity with regard to the development of flexibility is therefore relatively low overall, and varies according to the technological bricks likely to be called upon.

DATA CENTER REDUNDANCY

Data centers have reserve capacity built into their design, which could also be used for flexibility purposes with, in theory, little impact on operations. The integration of component redundancy into the design of data centers guarantees continuity of service in the event of one component failing.

This redundancy applies to both the UPS and the backup power supply. Sometimes the reserve capacity is equal to the operating capacity ("2N" model), sometimes it is ("2N" model), sometimes it is less (for instance "N+1" model). The flexible capacities identified in Chapter 3 are based on the capacity of computer racks, and do not take this level of redundancy into account.

This report has not taken these redundancy capabilities into account.

FLEXIBILITY IN OTHER COUNTRIES

Analyses carried out for five European countries by *BloombergNEF* confirm the wide gap between installed capacity, potential capacity and flexibility capacity that data centers will actually be able to mobilize in 2030.
The ratio is approximately:

- 7 for the United Kingdom, with the highest installed capacity (7,392 MW) and only 1,035 MW available for mobilization;
- 8 for Germany (5,643 / 657 MW);
- 6,1 for Norway (1,136 / 186 MW);
- 5,8 for the Netherlands (5,521 / 940 MW);
- 4,8 for Ireland (4,768 / 994 MW).

However, these figures for mobilizable capacity must be set against the actual flexibility needs of these countries, or against other sources of flexibility. By way of comparison, *BloombergNEF* indicates that Germany would need 550 MW for frequency support in 2030.

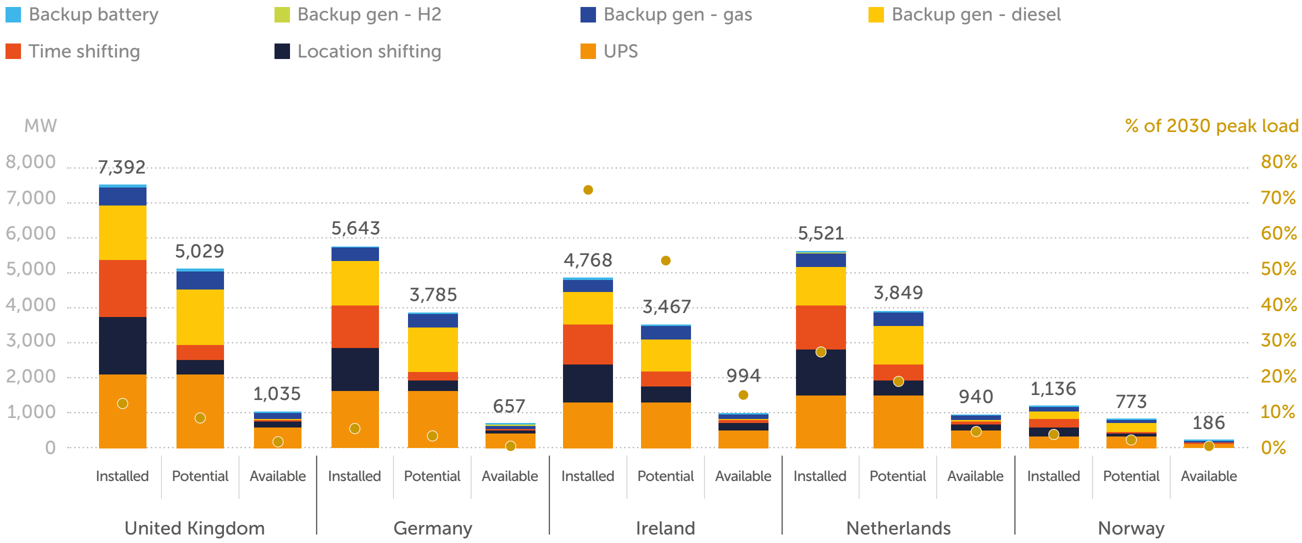
It should be noted that, as expected, the biggest discounts between potential capacity and available capacity are in countries with mostly colocation centers, and few large-scale data centers (*hyperscale*).

The particular case of Ireland is characterized by the fact that its 994 MW of mobilizable flexibility capacity in data centers could satisfy 15% of the country's peak electricity demand, while the other four countries are around one percent.

Faced with a lack of visibility on future computing demand, and therefore on energy demand, data center operators always keep a reserve to cope with a sudden increase in computing tasks. Access to this reserve capacity could provide a test bed for exploring data center flexibility. To this end, and in general to maximize flexibility potential, data center operators will need to develop better load forecasting capabilities.

In the following paragraphs, the mobilizable potential of each flexibility solution is estimated in the light of these constraints. **Given the many uncertainties involved, these projections should be read as orders of magnitude rather than precise assessments.**

DATA CENTER FLEXIBILITY BY COUNTRY BY 2030



Source: BloombergNEF

UNINTERRUPTIBLE POWER SYSTEMS

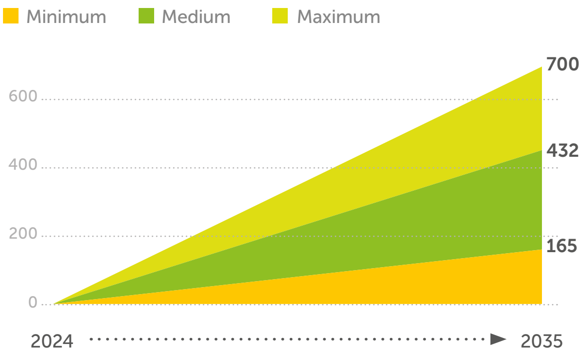
A UPS has many of the same performance criteria as a grid-connected battery, such as fast ramp rates. Although the reduced autonomy of a UPS limits its potential in energy markets, it is well suited to ancillary services.

The latter are generally called upon in the event of major deviations in system frequency, such as when a large power plant unexpectedly shuts down. As a result, they are not often used, but are put in place as a safety measure. These low risk occurrences are therefore likely to allay concerns about a possible reduction in power supply safety margins or premature wear and tear. It should be noted, however, that unlike the countries of Northern Europe, Germany and Italy, France's transmission system operator RTE estimates that at this stage, the need for "frequency support" will remain low in France, and is already largely covered by existing installations, notably stationary batteries.

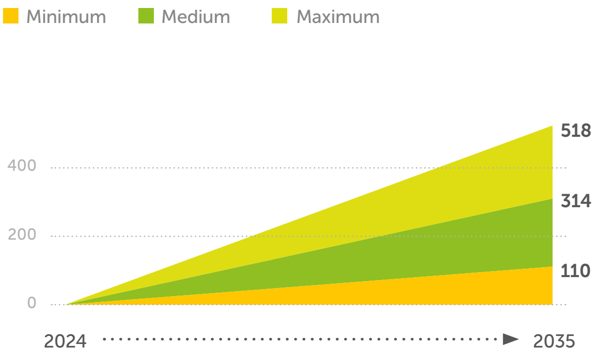
The economic value potentially offered by this flexibility service alone could prove insufficient to convince operators to commit to it.

In a communication dated April 8, 2024, RTE launched a call for interest as it "*plans to multiply voltage control points using consumer customer technologies enabling dynamic and continuous voltage control*" in certain tense areas including the Île-de-France area. UPS systems are theoretically capable of providing this service, but it will be necessary to integrate[25] "*network codes*", like the inverters used in renewable installations.

UPS - VOLTAGE SUPPORTS (MW)



UPS - FREQUENCY SUPPORTS (MW)



We conservatively consider that only 5% to 10% of the equivalent IT power available in 2035 would be devoted to flexibility for frequency support via UPS, i.e. between 110 and 220 MW in the low scenario for growth in the data center sector (see chapter 1.3) and 259 to 518 MW in the high scenario.

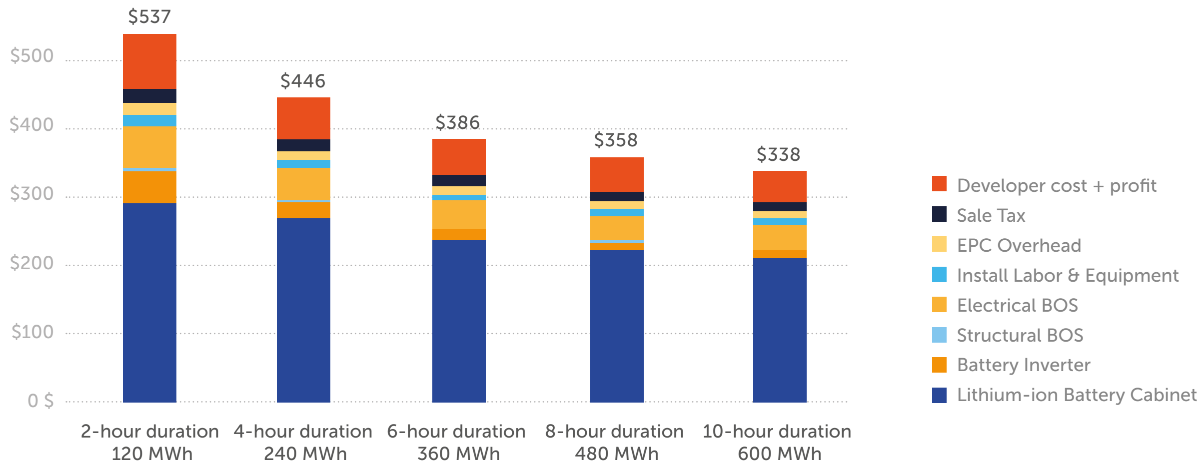
For voltage support flexibility, where the grid operator's interest may be greater, the range adopted is 7.5% to 15%, leading to a potential capacity of 165 to 330 MW for the low scenario, and 350 to 700 MW for the high scenario (in the latter case, it is assumed that only data centers in the Paris region will be used, i.e. 90% of the total).

[25] or grid code: document that defines the conditions required for an electrical energy producer or consumer to be able to connect to an electrical grid.

BATTERY ENERGY STORAGE SYSTEMS

The addition of a "stationary battery storage" function lasting 2 to 3 hours (the most interesting timeframe according to RTE), as opposed to the usual 5 to 15 minutes, has the advantage of making it possible to mutualize the costs involved in implementing the "UPS electrical back-up", as well as enhancing the economic value of an asset that until now has only been used for back-up purposes.

COSTS OF A 60 MW LITHIUM-ION STATIONARY STORAGE SYSTEM (USD/KWH, 2021)

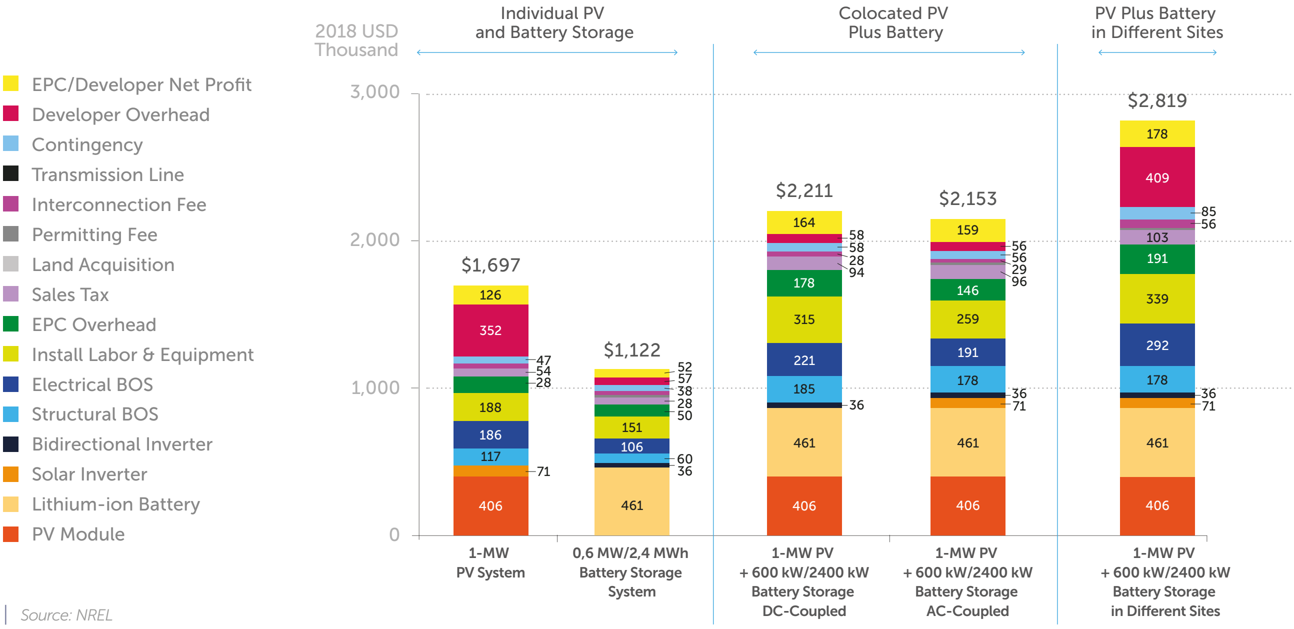


Source: NREL

In the United States (see graph above), the costs associated with lithium-ion batteries represent only 50% of the total cost of a 2-hour stationary energy storage system, the minimum window of economic interest for RTE. The cost structure is obviously different in Europe and France, and specific costs (battery chargers, converters, space requirements) may need to be factored in.

According to the National Renewable Energy Laboratory, a mutualization approach between a solar installation and a stationary storage system (BESS) could reduce the investment cost per kilowatt-hour by 25%.

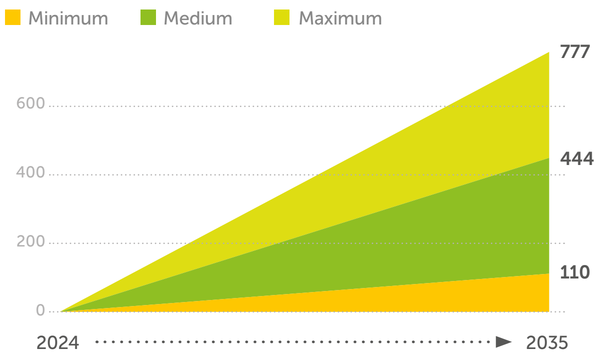
COST ESTIMATES FOR COMMERCIAL SOLAR PHOTOVOLTAIC AND BESS SYSTEMS, INDIVIDUALLY AND COUPLED TOGETHER



Source: NREL

It should be noted that two types of installation are possible: one allowing all or part of the data center to be "erased" from the grid, and the other also allowing electricity to be fed into the grid. In addition to requiring a larger battery bank, the second option also requires the installation to be compatible with "network codes".

BESS (MW)



In 2022, Google inaugurated a 2.75 MW / 5.5 MWh battery storage system at its Belgian data center campus[26] .

The company's objectives are to replace some of its generator sets and provide the power grid with flexibility services.

In view of the benefits that data centers could derive from flexibility (see chapter 4), including optimized electricity purchases on the market, and lower grid connection costs in exchange for availability of flexibility services, we estimate that the equivalent of 5% to 15% of available IT capacity in 2035 would be devoted to this through stationary batteries. That's 110 to 330 MW for the low scenario, and from 259 to 777 MW for the high scenario.

[26] https://www.datacenterdynamics.com/en/news/google-picks-fluence-for-275mw-grid-supporting-battery-system-in-belgium/

COOLING

The development of cooling-based flexibility services offers many advantages, but is also likely to give rise to varying degrees of complexity.
Varying the setpoint temperature in server rooms upstream and/or downstream of the network constraint is relatively straightforward. The difficulty lies in the contractual commitments (maximum temperature in the rooms) between the service provider and its customer, some of whom use old servers and are therefore likely to be sensitive to excessively high temperatures. Given the complexity of obtaining the agreement of all customers, regulatory intervention may prove necessary.

When it comes to cold storage systems (ice or phase-change materials), there are several factors to consider:

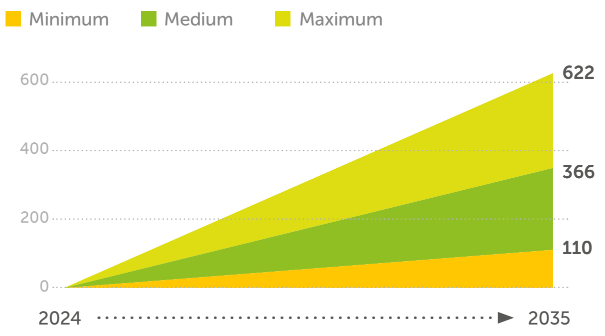
- the addition of storage systems quite logically generates additional costs, both in terms of equipment (temperature regimes different from "traditional" computer room cooling) and space occupied;
- electricity consumption for ice production, which is less efficient than fresh air generation, will reduce the energy efficiency indicator.

Seasonal variations mean that the cooling needs of data centers in France are greatest during the summer months. These "hot" periods will therefore be more conducive to modulating frigories production to meet power grid flexibility needs. They will be all the more propitious as, in the electricity system of 2035, electricity production from renewable sources will be significant in the summer, with potentially strong variations and extremely low, or even negative, prices during the afternoon.

In view of its weight in a data center's electricity consumption, and the fact that it can already be modulated to adapt to outside temperatures, cooling systems offer three types of flexibility:

1. in response to demand from the electrical grid, an upward variation in the setpoint temperature in the computer rooms would reduce the need for cooling, and therefore reduce the electricity consumed by the chillers. This flexibility would not require any additional investment, and would respond to short modulation times;
2. in response to demand from the electricity grid, modulation of cold storage to consume electricity (cold production) or to be removed from the grid (storage discharge). In the case of upward modulation, the duration of flexibility will be short - of the order of half an hour - and only possible if the ice storage is not entirely full; in the case of downward modulation, the duration could be longer, but must not impact the cold backup capacity for the data center;
3. for internal tariff optimization, cold storage production can be adjusted in line with electricity prices, if justified by the price differential between different periods.

COOLING (MW)



We estimate that the equivalent of 5% to 12% of the IT capacity available in 2035 could be mobilized for flexibility via modulation of the power supply. cold production, i.e. from 110 to 330 MW for the low scenario, and from 259 to 622 MW for the high scenario.

COLD STORAGE: THE CIV EXAMPLE

Latent cold storage is a limited but real practice in France. This is the case, for example, of operator CIV. There are several reasons why it has adopted this solution:

- it provides additional security in the event of a power failure, since the latent storage can take over for around 1 hour in the event of a shutdown of the chillers;
- it reduces the CO_2 impact of generator tests by eliminating the need to power chillers, which are put on stand-by during these periods;
- it offers the possibility of increasing temperature regimes and thus improving the data center's energy efficiency.

GENERATOR SETS

Converting standby generators into systems that can meet flexibility needs involves a number of technical changes with associated costs that can be significant:

- first of all, it is necessary to equip present and future installations with flue gas treatment systems (optional if the unit is only used as a back-up), which entails additional costs and the availability of space to accommodate them, not always initially planned;
- we also need to adapt the electrical infrastructure of the data center. This change may be relatively slight if we expect the groups to "erase" (or "remove") the data center demand (MW) from the network. It can be much more substantial if it is also asked to inject the remaining available electrical power. At present, existing and future data center designs do not offer this possibility.

The question of social acceptability also arises: even when acoustically treated, generators inevitably produce noise pollution when they are in use. Longer operating times can generate local opposition in highly urbanized areas.

Finally, there's the question of fuel and environmental issues. Solutions based on second-generation biofuels are now available on the market, and are compatible with existing and future generator sets: many data center operators have already converted to this type of fuel.

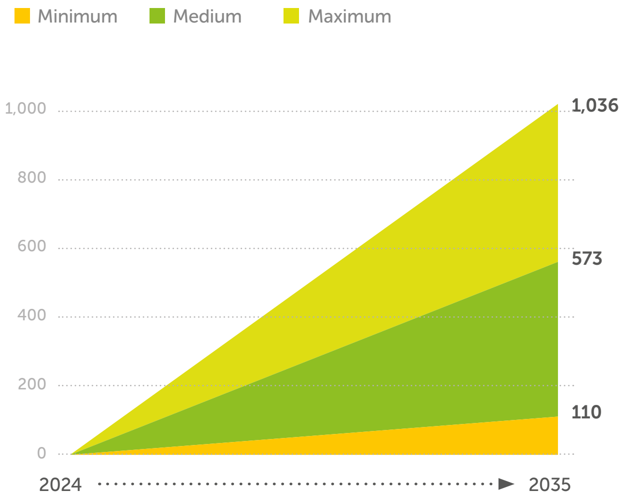
Their use in the context of flexibility services raises a number of questions:

- the ability of biofuel producers to meet any higher demand from generators, which would run longer and more regularly;
- the long-term price of these biofuels;
- the priority to be given to replenishing data center facilities, an essential condition for reassuring operators.

A dialogue between players in the biofuel production sector and those in the data center sector needs to be launched here.

With these barriers removed, gensets could eventually assume their pre-2014 role[27] and once again become major contributors to flexibility markets.

GENERATOR SETS (MW)



We estimate that the equivalent of 5% to 20% of the IT capacity available in 2035 and also available in the form of generators could be mobilized for flexibility, i.e. 110 to 440 MW for the low scenario, and 259 to 1,036 MW for the high scenario.

[27] Before they were excluded from load shedding mechanisms in 2014, up to 30% of installed generating capacity was involved

TIME SHIFTING

The notice period and associated time lag make time shifting and geographical transfer suitable flexibility levers for energy market operations such as peak shaving or adaptation to renewable energy production, but relatively incompatible with system services that require a rapid response.
Today, it is not natural or self-evident to shift data center loads over time, particularly in the absence of incentives. Operators and users of data centers need to be given the right signals to encourage time shifting, and to design software and applications with this in mind.

The issue is also more complex for colocation data centers than for hyperscale ones: a colocation provider can't see or control computing tasks, whereas hyperscale operators can manage their internal applications.

In France, where the colocation model is predominant, the data center operator can adopt an energy infrastructure to generate flexibility potential, but its full exploitation requires an alignment of control between the customer and the services provider.

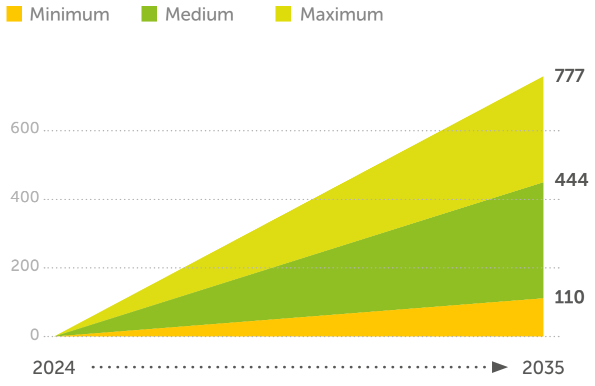
GEOGRAPHICAL TRANSFER

Until now, spatial displacement has been entirely up to the customer, who can decide to move his IT load according to the constraints of the electrical network of the data centers where his servers are housed, whether in France or Europe.
However, it is worth noting the recent development of Data Center As A Service (DCAAS) offers, which enable service providers to use their fleet of data centers to relocate geographically, while providing the same service to their customers.

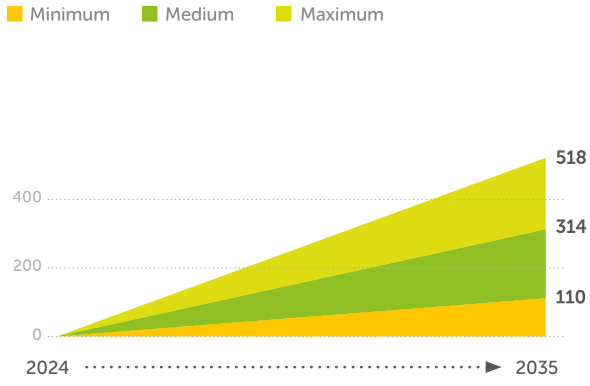
In this way, the major global colocation players could also geographically relocate the IT workload of their DCAAS customers.

In addition, when implementing a geographical transfer, consideration should be given to whether data can be moved outside a jurisdiction or country, for example due to data privacy governance or national security. This data limitation may not be significant (for example, in the case of movements within the European Union), but data center operators should keep this limit in mind.

TIME SHIFTING (MW)



GEOGRAPHICAL TRANSFER (MW)



In principle, 30-50% of IT tasks in data centers could be time-shifted[28] . But given the uncertainty of actually implementing this practice in colocation data centers, we estimate that 5% to 15% of available IT capacity in 2035 could use time-shifting flexibility, i.e. 110 to 330 MW for the low scenario, and 259 to 777 MW for the high scenario.

We estimate that the equivalent of 5 to 10% of IT capacity available in 2035 could be made flexible by shifting IT tasks geographically, i.e. 110 to 220 MW for the low scenario, and 259 to 518 MW for the high scenario.

[28] www.eaton.com/content/dam/eaton/company/news-insights/energy-transition/documents/bnef-eaton-statkraft-data-center-study-en-us.pdf

FLEXIBILITY POTENTIALS REVIEW

The growth in the number of data centers in France between now and 2035 positions this sector as a significant consumer of electricity. But beyond consuming less, there is also consuming better: flexibility, through the value it could represent not only for the data center sector and its customers, but also for the energy sector, merits in-depth examination.

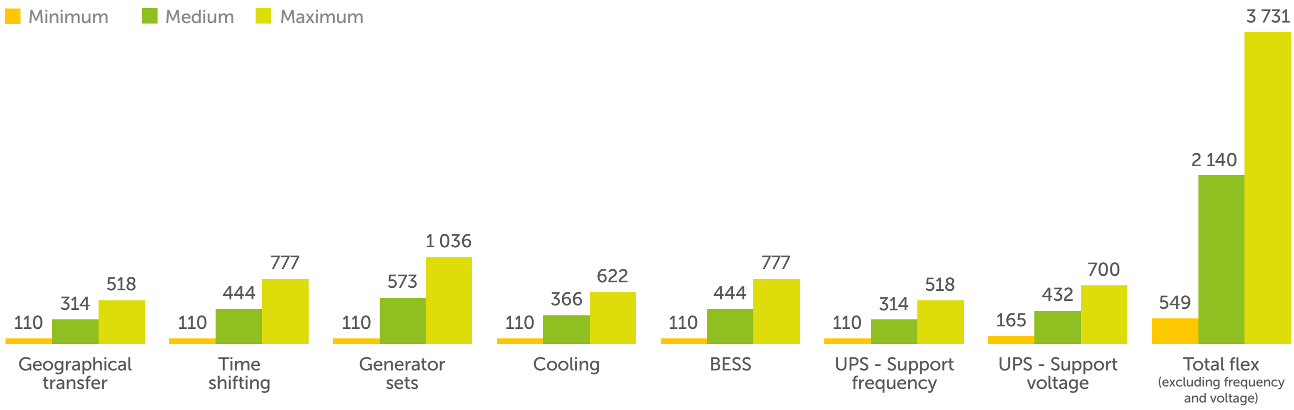
In France, colocation sites are likely to remain the main model. Their operators have less latitude than hyperscale data center operators to apply flexibility measures in practice. These need to be anticipated with customers, not only from a contractual point of view, but also from a technical one, in relation to the grid, design and site constraints (notably land), and of course from a financial point of view, in relation to the operator's profitability objectives.

On the other hand, newly built data centers or new active server capacities are more likely to be flexible than existing ones.

New installations are more likely to be equipped with the control and communication systems needed to operate with flexible services. Similarly, new backup power technologies, such as large-capacity batteries or decarbonized generators, will be installed in new sites. Existing ones may be equipped with these new technologies, but at a higher cost.
The estimates made in this report are therefore conservative but realistic, and are based on the various flexible resources available in data centers.

The theoretical flexibility potentials available in 2035 are summarized in the following graph.

TOTAL FLEXIBILITY POTENTIAL FOR DATA CENTERS BY 2035 (MW)



NB: *frequency and voltage support potentials are not included in the total, as they correspond to a very specific need for flexibility (balancing).*
Editor's note: *the simplicity of the assumptions made should encourage the reader to consider the values shown for what they are: orders of magnitude. Of course, GIMELEC looks forward to further work that takes into account all the complexities of the sector.*

In cumulative terms, the lowest assumptions would reach 549 MW of flexibility capacity in 2035 in data centers, while the highest assumptions would cumulate to 3.7 GW. Of course, it's unlikely that all flexibility resources will be activated simultaneously, if only because UPS systems won't handle frequency and voltage at the same time, or because generators won't be started up in the summer when upward modulation of cooling production will take place thanks to an overproduction of renewable electricity.

Nevertheless, the potential remains very significant for the French power grid. An average level of 2.1 GW of flexibility can be assumed. This corresponds to 70% of the current level of industrial load shedding in France.

[29] In the event that the ambitious assumptions on nuclear power and sobriety are not met. See the main results of the Balance Forecast, page 52: https://assets.rte-france.com/prod/public/2023-10/2023-10-02-bilan-previsionnel-2023-principaux-resultats.pdf

KEY FIGURES DATA CENTERS
FLEXIBILITY POTENTIAL

3.7 GW

highest assumption
of accessible flexibility
capacity in 2035

549 MW

lowest assumption
of accessible flexibility
capacity in 2035

2.1 GW

median hypothesis
of accessible flexibility
capacity in 2035

= 70%

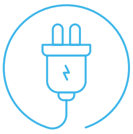
of the flexibility
provided by french
industrial customers

4

THE BENEFITS OF FLEXIBILITY FOR DATA CENTERS

Data centers are more energy-efficient than personal computers, and overall, they reduce energy consumption for computing tasks. They are a key element in the digital economy of the 21^{e} century, and this sector is already making significant efforts to reduce its greenhouse gas emissions. Flexibility is the next step if data center operators are to contribute to the acceleration of electrification in France

Previous analyses show that the technical potential of data centers in terms of flexibility is real. But the actual capacity available is likely to be lower, as it depends on the willingness of data center operators and their customers, and on the associated operational complexity. The priority for colocation operators is, and will remain, to provide uninterrupted, high-quality service to their customers who have signed up for access to an IT infrastructure.
Voluntarily and regularly using their backup systems (UPS, generators), controlling their cooling systems, or even modulating the availability of their digital infrastructures according to calls for power grid flexibility or price signals is an idea that is gradually gaining ground. In particular, it needs to gain in maturity in terms of the operational conditions for implementing such flexibilities, and the benefits - particularly economic - that data center operators and their customers can derive from them.
They can consider several advantages to providing flexibility services to the grid through their energy systems:



Grid access advantages

committing to providing flexibility to the grid can lead to cheaper and faster connections, thanks to the reduction in work involved infrastructure reinforcement required

Financial benefits

a data center's energy bill can be reduced by optimizing energy consumption in line with electricity prices and network costs, and/or by providing paid flexibility services to the network

Environmental benefits

even if the carbon footprint of a kilowatt-hour of electricity in France is low, there is an advantage in aligning electricity consumption as closely as closely as possible to the reality of the energy mix.

These benefits need to be seen in the context of an electricity system that is set to evolve significantly over the next decade, with the development of renewable energies and an increase in the number of uses for electricity (re-industrialization, heat pumps, electric vehicles, hydrogen production). Data centers represent an ever-increasing amount of electrical power, and their continued development will contribute to this additional pressure on the system.
Acting proactively to reduce their impact from time to time, thanks to flexibility in power and energy, is also a way of positively accompanying public authorities on the cresting path formed by the growth of digital combined with the energy transition.

4.1 REDUCED NETWORK CONNECTION TIMES AND COSTS

As the number of data centers grows, their operators are faced with a major challenge: getting their sites connected to the power grid. New connections in geographies where networks are congested are increasingly costly and time-consuming

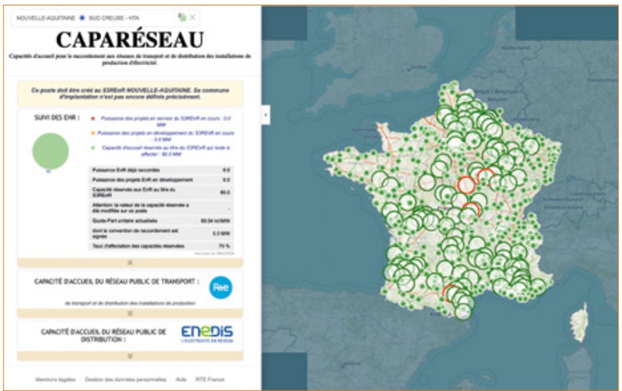
Given their high electrical demand, data centers can absorb a large proportion of the network's available local capacity, forcing network operators to reinforce it. For example, network upgrades may include upgrading a substation or building new power lines.
What's more, data center operators sometimes require separate connections to several substations, to guarantee redundancy in the event of failure.

Securing grid capacity can be a greater challenge for data centers than for other industrial electricity users, as they generally wish to locate close to densely populated cities. However, grid capacity in urban areas is sometimes already limited due to high electricity consumption, and upgrading the local infrastructure can be more difficult than in rural areas. In some countries, this capacity may even be reaching a saturation point.

Grid operators publish maps to identify areas with available grid capacity. In France, for example, RTE does this via the capareseau.fr website, as part of the regional grid connection plans for renewable energy.
It's an interesting tool for data center operators looking to locate new projects.

Applying for and obtaining a new grid connection can take a long time: from 2 to over 9 years, depending on the voltage level of the grid connection. The assessment, design, authorization and construction of a new connection can take years (see Preamble), which is a very long time compared to the needs of data center operators.

As a result, they tend to make speculative or "development" connection requests. Developers with land apply for planning permission and connection to the network to prepare a site for a future data center.
There's no guarantee that the data center will be built at all, but this "excess demand" gives the operator some security for the future. Conversely, as the network operator must examine all connection requests made to him, he finds himself under severe constraints when it comes to integrating these oversized capacity requests into his network.



CAPARESEAU.FR

Site developed by RTE to provide information on the possibilities for connecting electricity generation facilities to the transmission and distribution networks.

CONNECTIONS THAT ENCOURAGE FLEXIBILITY

To help solve this problem, contain costs and/or speed up data center connection projects, flexibility is a lever available to network operators and data centers. This involves the use of smart connection operations (SCOs), which aim to "*optimize the sizing of connection facilities, or the time required to commission a user's connection. In return, the connection applicant agrees to have part of its production or consumption capped during certain periods, or to receive a connection solution at a lower power than that requested, while allowing additional injections or extractions during certain periods*[30]".

According to CRE, "*smart connection offers are emerging as an innovative solution for connection applicants. They are an effective way of optimizing the sizing of facilities and reducing connection commissioning times. In this way, the applicant can agree to specific injection or extraction limitations in the event of network constraints, to benefit from less costly and/or a faster connection*".
For example, network operator Réséda in Metz has experimented with the connection of a wind farm incorporating selective limitations on injection in order to optimize the ratio between investment and injectable yield.

This connection offer resulted in a saving of 730 k€ compared with the reference connection, or 42% of the connection costs.

Previously reserved for renewable energy production facilities, connected on the low-voltage network mainly operated by the french distribution system operator Enedis, SCO have been offered by RTE to large consumers since 2022. This extension has been welcomed by the CRE, which is calling for these offers to become widespread.
In the Ile-de-France region, for example, where demand for data center connections is highest, RTE is carrying out work to reinforce the extra-high voltage (400 kV) network, which will continue until 2030. It also has to deal with constraints on the regional 225 kV network, which complicates connections. Against this backdrop, the grid operator has introduced "*early*" connection offers, which are often chosen by project developers. They enable data center projects to be connected more quickly, provided that they accept a possible curtailment of extraction of up to 1,200 hours per year during the reinforcement work.
In the Bouches-du-Rhône region, RTE is also experimenting with pooled connection solutions where several consumers can share studies, links and transformer substations, in order to reduce connection costs.

[30] Definition taken from the glossary at https://www.smartgrids-cre.fr/glossaire#ori

4.2 LOWER ELECTRICITY BILLS

A data center's electricity consumption is the sum of the power consumed by its servers and the power consumed by the center's "utilities" (secure power supply and cooling).

Today, colocation operators are adopting several models to integrate the cost of electricity into their services:

- flat-rate billing of electricity to the customer, based on an assessment of annual consumption. This solution is aimed at customers with the lowest IT costs;
- metered billing, i.e. billing based on meter readings. In this case, there are two possibilities for setting the price per kilowatt-hour: either a fixed price agreed with the customer at the beginning of the year, or a price that varies with the seasons, or even every month. The latter solution, known as "*pass-through*", can even be based on electricity spot market prices;

***NB:** In their contractual relationship, there is generally a reciprocal commitment between the customer, who undertakes to respect a certain level of IT workload, and the operator who commit to a certain PUE performance*

Market electricity prices in Europe are increasingly impacted by the growing share of renewable electricity in France and Europe.

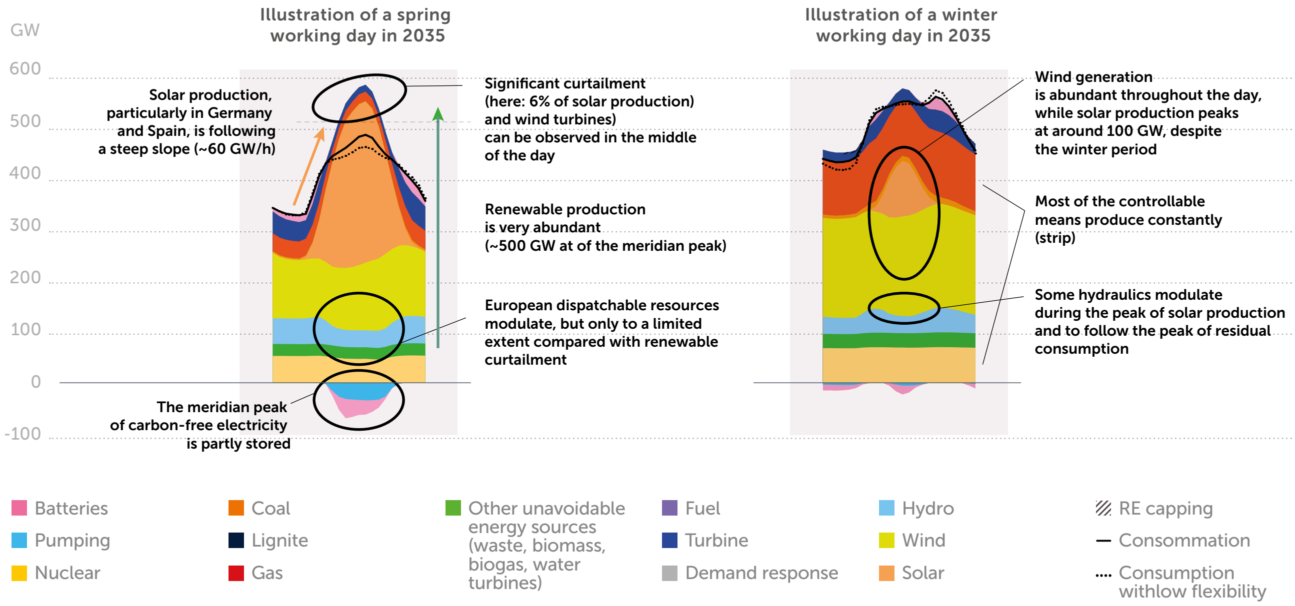
They can also change rapidly as a result of unforeseen events (e.g. war in Ukraine, immobilization of part of the nuclear fleet in 2022). Electricity prices are becoming increasingly volatile. A trend is emerging with a steady increase in the number of days with low (or even negative) prices in the spot market in the middle of the day and higher prices to start or end the day. The graph on the following page illustrates this based on data from RTE's Eco2mix (example of a day's prices on the spot market in France).

This is partly due to the fact that there is now a diurnal peak in photovoltaic solar production, sometimes supplemented by wind power.

A large supply of electricity at this time, without any particular increase in consumption, lowers market prices. This phenomenon is set to intensify as renewable energy production capacity increases.

In RTE's projections to 2035 (see graph below), this effect will be very strong in summer, but also significant in winter.

EXAMPLE OF HOW THE EUROPEAN POWER SYSTEM WILL FUNCTION IN 2035



Source: RTE

To meet this challenge, it will be increasingly useful to control loads, by shifting consumption at the time of these production peaks. The flexibility that could be provided by any large consumer - such as a data center - is a service that needs economic and/or regulatory incentives.

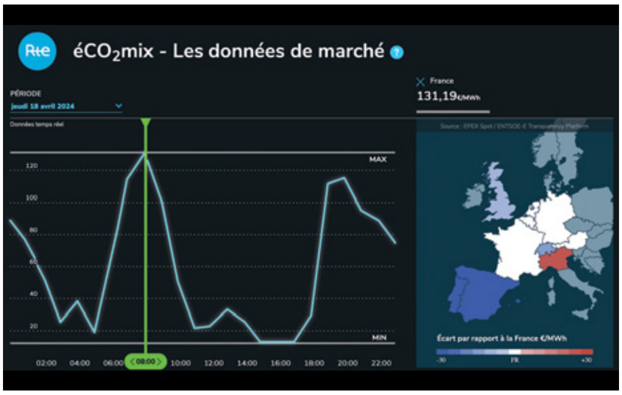
On the economic side, there are two levers to consider:

- Some flexibility services can be remunerated: frequency and voltage management, explicit load shedding, balancing mechanisms (see chapter 2.1). As we saw in chapter 3, data centers have the means to meet some of these flexibility needs. The frequency and volume of these services must provide the operator with sufficient remuneration in relation to the additional investment required to implement them.

1. The price of electricity is an important lever for encouraging flexibility. It's important to remember that today, this price is roughly broken down into three parts. In addition to taxes, there are:
    - a supply component: data center operators can choose to modulate the IT load directly in line with market prices, with daily price differentials now reaching almost €100/MWh (see box for example);
    - a "network" component: the French Energy Regulatory Commission supports a more proactive policy of "peak/off-peak" tariffs, which provide a much greater incentive to manage loads. This will be reflected in the next grid tariffs, to be implemented in 2025 (the "grid financing" part of the overall price of electricity kWh). For example, CRE is considering the introduction of off-peak hours in the summer between 2 a.m. and 6 a.m., and again between 12 p.m. and 4 p.m.[31] .
    The addition of a storage component to the grid tariffs calculation is also envisaged to encourage "counter-cyclical" projects.

In any case, whatever the financial relevance of an economic or regulatory signal, the question arises of how to transfer the price signal between colocation operators and their customers. With the current trend towards a "*pass-through*" model, colocation customers are often the most (if not the only) with incentive to become more flexible. This means that contractual work needs to be carried out to share this signal with the data center operator, so that the latter is also encouraged to implement flexibility services.

EXAMPLE OF A PRICE DAY ON THE SPOT MARKET IN FRANCE (SOURCE RTE)



A NEW MARKETPLACE FOR CARBON-FREE ELECTRICITY

In the USA, major digital players such as Google and Microsoft are part of a consortium that will test an hourly supply of decarbonized electricity. The *Granular Certificate Trading Alliance* has been launched by LevelTen Energy[32] and will be based on a platform where buyers and sellers of electricity can trade, 24/7.
The aim is to provide access to a market that reflects, on an hour-by-hour and localized basis, the decarbonized production of mainly renewable electricity. Consumers will thus have access to certificates to justify their zero-carbon supply, with a fine granularity over time.
Producers will be encouraged to invest in resources that will enable them to better meet this demand at times when consumers need them. Means of production that do not yet benefit from certificates, such as energy storage, will also find an outlet on this platform.

EXAMPLE OF GAINS THANKS TO PRICE DIFFERENTIALS ON THE MARKET

Let's imagine that a 100 MW data center shifts 20% of its load from morning (7am-9am) and evening (7pm-8pm) to lunchtime (12pm-3pm) on June 6, 2024. Based on EPEX SPOT prices, the potential savings on the supply side would be around €6,000.

Assessing potential gains on grid tariffs is more complex, since peak and off-peak tariffs vary according to contract type, voltage level and season. In terms of order of magnitude, increases/decreases can vary between 15% and 40% (i.e. between 5% and 15% of the total price per kWh).

[31] https://www.cre.fr/fileadmin/Documents/Consultations_publiques/import/231214_CP_2023-13_Structure_TURPE_7_HT_et_HTA-BT.pdf
[32] https://www.datacenterdynamics.com/en/news/google-and-microsoft-back-247-carbon-free-energy-marketplace/

4.3 REDUCING GREENHOUSE GAS EMISSIONS

Flexible data center operation can reduce greenhouse gas (GHG) emissions from the data center itself, while helping to reduce emissions from the power system as a whole.

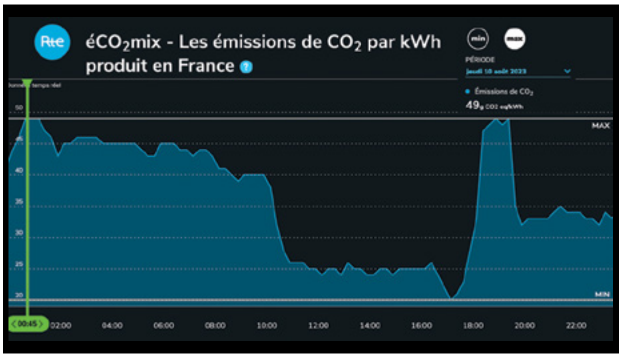
Reductions can come from:

- CO_2 arbitrage, shifting energy consumption to times when the carbon intensity of electricity production is lower. With a little forethought, a data center operator can reduce GHG emissions by shifting the digital load from one period to another, mainly when renewable energy production is high. Shifting the load would also generate savings, as periods of high renewable energy production generally coincide with periods of lower electricity prices (see previous chapter);
- carbon arbitrage based on geographical location: shifting the consumption of a data center located in a country or region where the network's GHG emissions are high, to a location where these emissions are lower. In France, where electricity is already highly decarbonized, this type of domestic shift is of little interest. However, we can imagine data center operators occasionally repatriating IT loads to France to avoid consuming high-carbon electricity from certain other European countries. It is also possible to imagine shifting consumption to an area with a very high level of renewable energy production, so as to avoid the need for the grid operator to shave this production;
- replacing fossil fuel generation: the data center can use a flexible, low-carbon resource to meet its energy needs at times when the CO_2 footprint of electricity supplied by the grid is greater.

In France, the low carbon footprint of a kilowatt-hour of electricity reduces the challenge of reducing CO_2 emissions from data center activities.

However, during winter peak periods, when the grid relies more heavily on fossil-fuel power plants, lowering a data center's electricity consumption can reduce its carbon footprint.

EXAMPLE OF DAILY VARIATIONS IN CO_2 EMISSIONS PER ELECTRIC KWH IN FRANCE (SOURCE RTE)



EXAMPLE OF A GEOGRAPHICAL TRANSFER

In February 2024, Google and the Cirrus Nexus company tested the geographic transfer of IT tasks from California to the Netherlands, which at the time benefited from high renewable energy production. The result was a 34% drop in GHG emissions[33].

CARBON BENEFITS OF FLEXIBILITY IN IRELAND AND THE UNITED KINGDOM

An Irish study[34] has shown that if carbon-free sources of flexibility, such as batteries or demand modulation, provide half of the required reserves (350 out of 700 MW) in the Irish electricity system, this will avoid the emission of 400,000 tonnes of CO_2 per year by 2030. This represents a saving of 1,200 tonnes of CO_2 emissions per MW of reserve capacity. However, in terms of carbon benefit, the return is diminishing: if 100% of reserves came from batteries and demand modulation, savings would halve to around 600 tonnes per MW. Furthermore, the study shows that if all reserves and other grid needs were met by decarbonized sources, the amount of renewable generation capped in 2030 would be halved, from 8.1% to 4%.

The economic potential of decarbonized sources to supply reserves to the grid has been demonstrated by the UK grid operator. National Grid ESO ran a three-year trial in 2020 in which four large batteries ranging from 41 MW to 49 MW supplied reserves to the system, in place of thermal power stations. The trial achieved its objectives and showed that £700,000 was saved on system service costs, as there were fewer payments to other conventional reserve suppliers.

[33] https://www.bloomberg.com/news/articles/2024-02-25/ai-increases-data-center-energy-use-google-pioneered-technique-could-help
[34] Storage, Respond and Save, 2019 : https://windenergyireland.com/images/files/iwea-baringastorerespondsavereport.pdf

5

UNLEASH THE POTENTIAL FOR FLEXIBILITY DATA CENTERS

Grid operators and regulators have long implemented mechanisms to ensure supply and demand balance:

- for several years now, grid tariffs vary according to the time of day during the winter period;
- some supply contracts, such as "Tempo" or "peak/off-peak", have adopted the same principle of time-seasonality;
- capacity markets ensuring the availability of a certain amount of power in the event of a problem have already been operating for several years in France.

Data centers will host large quantities of flexible resources by 2035, but not all of them can be exploited. This is illustrated by the large discrepancies between the low and high estimates discussed in section 3.

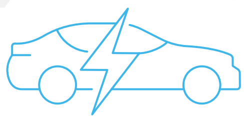
Access to these resources nevertheless presents significant opportunities. Data center operators can play an active role in the electricity sector's transition to a low-carbon economy, while optimizing their energy costs.

They can provide grid operators access to more flexible resources to ensure the resiliency of the power system, optimize their costs, and smooth out their investments.

To unleash its potential for flexibility, the sector now needs to open up a number of new avenues.

In France, data centers are covered by specific regulation aimed at making the flexibility of their power units available to help balance the electricity system, following the 2022 crisis (see chapter 3.3).

This could become even more the case in the future, as data center capacity expands, renewable energies take off, and other sectors such as transport and buildings make increasing use of electricity.



5.1 EVOLVING CONTRACTUAL MODELS

The primary mission of colocation operators is to provide their customers with reliable infrastructure to support data storage and processing.
Many operators therefore feel that any move towards flexibility risks interfering with this primary objective, either through lower computing performance, less reliable service or premature aging of their equipment. For these reasons, and because they are a complex industry, they are often reluctant to explore flexibility.

Data center operators and their customers have precise Service Level Agreements (SLAs) which define performance expectations, such as latency, processing speed, uptime and storage capacity, etc. In addition, these SLAs generally require operators to report to their customers any incidents and energy security system triggers.
What's more, these SLAs generally require operators to declare to their customers any incidents and triggering of energy security systems.
As a result, many operators fear that any flexibility action will contravene SLAs.

As the French market is almost exclusively colocation-based (and is set to remain so, at least in the medium term), the development of flexibility will inevitably require the emergence of specific SLAs or "green SLAs". In particular, these will have to modify mutual responsibilities across the entire technical flexibility chain and the sharing of the value derived from it (see next page). In addition to its customers, a data center operator also has agreements with subcontractors and other stakeholders who may also be directly impacted.

However, the industry is not starting from scratch. During the winter of 2022/2023, data center operators in France were required to make generators of over 1 MW available on the balancing mechanism, requiring discussion between colocations and their customers.
SLAs generally require minimum stocks of 48 to 72 hours of fuel autonomy and systematic notification when these generators are launched, so contractual modifications had to be made to comply with the law.

In this rearrangement of contractual habits, the data center operator could call on a third-party service provider, or a virtual power plant operator (aggregator), to exploit the data center's flexible resources on the markets. This would be tantamount to entrusting partial control of an asset to an outside party, raising questions about site security and operational limits.

SLAs can encourage or discourage colocation customers and operators from adopting greater flexibility. Work on their design, integrating the effects of flexible operation, could facilitate the operational implementation of flexibility in the sector.

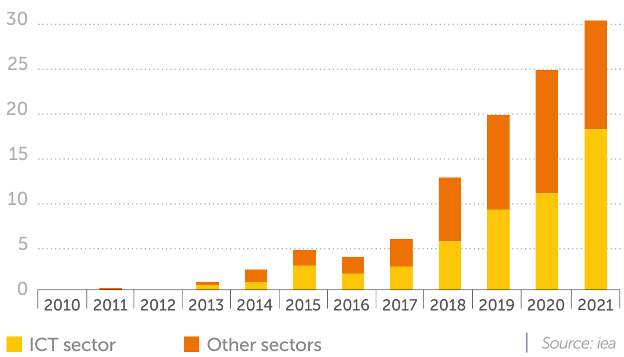
5.2 PROMOTING DIALOGUE BETWEEN ENERGY PLAYERS AND DATA CENTERS

Data centers are an electricity-intensive industry. Therefore, data center competitiveness depends on their ability to secure low-cost, long-term electricity supplies.

As with most French electro-intensive players, data centers rely heavily on ARENH (Accès Régulé à l'Electricité Nucléaire Historique).
This scheme, which up until now has provided data centers with access to low-cost electricity, is due to expire without any replacement. French industry has therefore entered a period of uncertainty.

In response, some companies have opted for Power Purchase Agreements (PPAs)[35], which guarantee a supply of green electricity at a fixed cost over a long period. This practice is widespread with the digital sector the leading "consumer" of PPAs[36].

RENEWABLE ENERGY PPA BY SECTOR, 2010-2021



In addition, Europe's energy crisis has created considerable turbulence for the sector, particularly in France, where electricity costs are set to rise sharply in 2022. Even if they have returned to relatively low levels today, it is likely that the exposure to risk was made clear.

However, European electricity markets, including France's, are undergoing significant structural change in the face of strong and steady growth in renewable energy production:
from late winter to late autumn prices are significantly lower in the afternoon than in the early morning, early evening or night. So there's real economic value to be exploited here.
The "insurance" value of a long-term supply contract should therefore be revisited and compared with the value potentially derived from a supply that takes advantage of these daily variations.

Another economic element are grid tariffs which represent on average 1/3 of a data centers electricity bill.

For several years now, grid tariffs has been "time- seasonalized", i.e. it is differentiated according to time of day and day of the week, to encourage customers to limit their consumption during the periods of the year when consumption by all consumers is highest. For the time being, seasonality is limited to the winter period, but the Commission de Régulation de l'Énergie, in charge of definition of the next grid tariffs scheduled for 2025, is considering the possibility of extending it to the summer periods:

CRE is also considering promoting electricity storage facilities via "*the possibility of introducing a new withdrawal/injection tariff for batteries. The aim of this optional pricing system would be to send out pricing signals that would enable storage capacity to be used to the best advantage for the grid. In this way, injection/withdrawal sites could be given an incentive to operate counter-cyclically to the pocket in which they are located (e.g., to inject when other users in the pocket are drawing heavily)*".

> "CRE's preliminary analyses [focus] on possible changes to peak/off-peak time slots to adapt to future developments, and in particular to take advantage of of the increase in photovoltaic production, while at the same time meeting the severe constraints of the power system at certain times of the day. CRE is therefore studying the possibility of giving priority to off-peak hours when production from renewable energies is abundant, as is the case on summer days. This could lead to an increase in the number of off-peak hours available in summer. Similarly, CRE is considering moving certain off-peak hours to times when high consumption could put pressure on the supply-demand balance. As a result, peak and off-peak hours could be differentiated between summer and winter, to suit seasonal needs of the electrical system." [37]

These ongoing upheavals in the "energy world" are being perceived in different ways in the data center sector, which is also undergoing its own profound changes, particularly in terms of the distribution of the electricity price signal (see page 42).

In the face of certain compartmentalizations and rapid changes in the worlds of energy and data centers, dialogue between the two must be promoted to facilitate understanding of the challenges and mechanisms of flexibility, and to stimulate innovation. New contractual practices are needed to encourage colocation customers to manage their IT load with flexibility in mind.

[35] https://www.equinix.fr/newsroom/press-releases/2024/01/equinix-et-wpd-concluent-l-un-des-plus-importants-contrats-d-achat-d-lectricit-verte-en-france-ppa-finan-ant-la-cr-ation-de-sept-nouveaux-parcs-oliens-et-la-d-carbonation-du-r-seau
[36] https://www.iea.org/data-and-statistics/charts/global-renewable-energy-power-purchase-agreements-by-sector-2010-2021
[37] https://www.cre.fr/fileadmin/Documents/Consultations_publiques/import/231214_CP_2023-13_Structure_TURPE_7_HT_et_HTA-BT.pdf

5.3 EMBRACING FLEXIBILITY IN CONNECTION AND PLANNING RULES

Offered by either Enedis or RTE, the Smart Connection Offer (or SCO) is an innovative connection option that is advantageous for the applicant, but subject to certain conditions (see chapter 4.1).

For data center operators, this provision reduces the time constraints that strongly structure the sector's activity and cuts the associated costs. For network operators, it means investments can be smoothed out over time and increases network asset utilization.

This type of connection is temporarily required in the Ile-de-France region. As RTE is reinforcing part of the 400 kV network (work is expected to be completed by 2030), all connection offers include a request for a commitment from the applicant to be able to switch off part of his consumption for up to 1,200 hours a year.

SCOs, which are very popular with renewable energy and energy storage projects, are strongly promoted by the CRE. Given the flexibility levers available to the data center sector, which are likely to meet the grid operator's needs, it seems important to explore this option further, without forgetting to include the contractual aspects required to map value and risk to the multiple customer stakeholders.

It should be noted that for Enedis, the savings on connection costs made possible by SCOs for producers are of the order of 90 k€/MW installed[38].

[38] https://www.enedis.fr/sites/default/files/documents/pdf/les-flexibilites-au-service-de-la-transition-energetique-et-performance-du-reseau.pdf

5.4 BETTER UNDERSTANDING AND COMMUNICATION OF ENVIRONMENTAL BENEFITS

Whether they're colocation operators or digital giants, most of the players in the data center market have publicly committed to significantly reducing their environmental impact.

This is reflected operationally in a number of ways, the most visible of which is the use of renewable energy PPAs; major technology companies are among the leading signatories to renewable project-based power purchase agreements. Some data center operators, such as Google and Microsoft, are taking the next step in their procurement strategies and aiming to match low carbon energy supplies to demand 24/7, a goal in line with further flexibility.

The data center sector lacks transparent data on energy consumption or GHG emissions. Tracking this data through grid operators would enable the industry and users to better understand their impact on the power system and the environment.

With a granularity of 15 minutes, for example, this data would enable data center users to adjust their calculation schedules. We could even imagine digital application designers planning an architecture that tolerates time lags or responses to market signals in real time.

This improved knowledge of flexibility and the framework in which it operates would be a source of innovation. Data center operators could charge their customers variable energy prices throughout the day to reflect electricity market conditions. This would encourage consumers to shift their load to the hours when costs are lowest, reducing the need for balancing on the grid or balancing of renewable generation.

As battery storage and demand modulation can provide services to the system, a standardized assessment of this benefit and its allocation to the various players would encourage data center operators, and their users, to mobilize flexibility resources.

CONCLUSION

Data centers are the keystone of the digital services we all use every day, and which our society can no longer do without. Data centers are now significant consumers of electricity at a grid-scale, with growth, in number and size, poised to remain strong over the next 10 years.

From the point of view of electrical networks, data centers create new needs in addition to those of existing industry which itself is becoming electrified, and those emerging from the reindustrialization and electrification of uses. Managing this transition in a cost-effective way while maintaining reliable operations is challenging for network operators.

Data center flexibility offers accessible solutions to part of this equation. With new solutions it is possible to reach almost 3.7 GW of flexibility in 2035. This white paper details the various strategies that can be implemented to realize this potential for flexibility.

The technological solutions are there, but the obstacles to their widespread use lie in the current organization of the data center world, even if a few initiatives are beginning to take root. If market practices and the regulatory framework are to converge in favor of flexibility, a genuine collaborative effort is needed on the part of data center operators, their customers, power grid operators and the regulator.

Data center energy flexibility is in everyone's interest to achieve acceptability, attractiveness, and competitiveness.

We gather
the electrodigital
companies.

Our 210 members design,
manufacture and deploy
the solutions for electrification,
automation and digitalization
for industry and buildings,
mobility, energy and digital
infrastructures.

We, GIMELEC Data Centers,
deploy the most innovative
technologies in order
to guarantee digital growth
for all, with a reduced
ecological footprint.

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