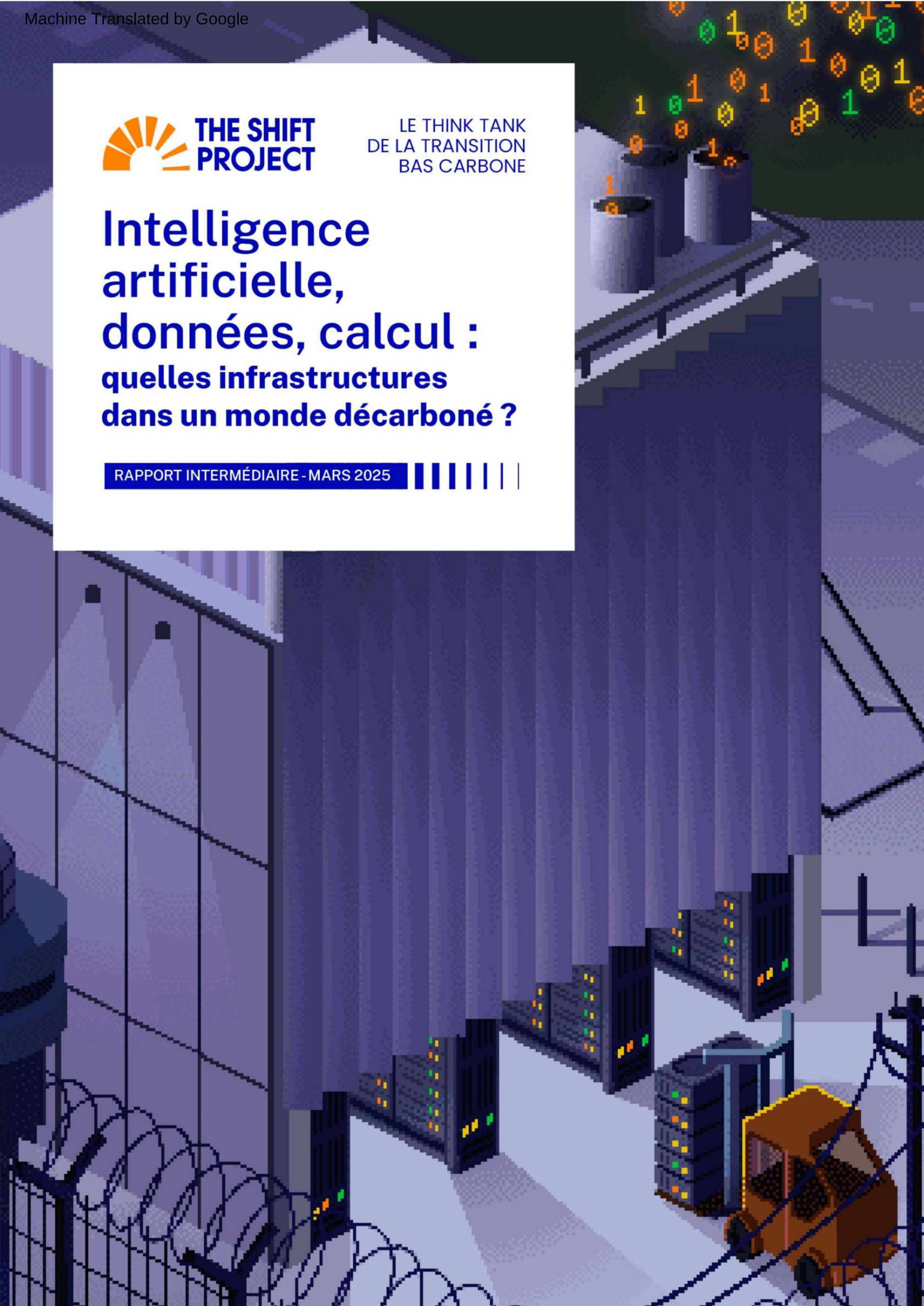
THE SHIFT PROJECT

LE THINK TANK DE LA TRANSITION BAS CARBONE

Intelligence artificielle, données, calcul :

quelles infrastructures dans un monde décarboné ?

RAPPORT INTERMÉDIAIRE - MARS 2025



About: The think tank The Shift Project (TSP)

The Shift Project is a think tank working towards a carbon-free economy. A non-profit organization recognized as being of general interest and guided by the requirement of scientific rigor, its mission is to inform and influence the debate on the energy and climate transition in Europe. Since 2010, it has been supported by major French and European companies, as well as public bodies, business associations, and SMEs. It is supported by a network of tens of thousands of volunteers grouped within a non-profit organization: The Shifters, created in 2014 to provide voluntary support to the Shift Project.

It aims to mobilize businesses, public authorities and intermediary bodies on the risks, but also and above all on the opportunities generated by the "double carbon constraint" represented together by tensions over energy supply and climate change. Its approach is thus marked by a particular analytical prism, based on the conviction that energy is a key development factor: therefore, the risks induced by climate change, closely linked to energy use, are of particular systemic and transdisciplinary complexity. Climate-energy issues condition the future of humanity; it is therefore necessary to integrate this dimension as quickly as possible into our model of society.

Your participation in the work: proofreading and contributions

The work presented here is exploratory: it aims to initiate new discussions and, on many topics, raises more questions than it answers. Although it is already the result of collective effort, this interim report is still an imperfect, incomplete, and evolving working document.

As you will see, the results of our quantitative analyses have not yet been fully realized. For future phases of work, any data sources that you find essential to integrate into our work will be welcome.

Your feedback will also be valuable on the entire document and the elements presented to you therein: methodology, general approach and choice of angles chosen are presented here to be submitted to the opinions of stakeholders on the subject of digital technologies, their decarbonization and their resilience issues.

In this context, we ask you to send your comments, criticisms and suggestions to the contacts indicated at the end of the report.

Of course, you don't need to read this entire long document to help us improve it: all contributions are welcome.

We need you!

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Table of Contents

Table of figures

Introduction

I. Digital technology, both a tool and a challenge for the decarbonization of the economy

Information technologies, now central to essential activities in our societies, could play a crucial role in transforming our economy. While digital equipment and the uses they enable —and promise—seem to be designed to meet ever-increasing challenges, this should not exempt them from consideration of their environmental relevance. Indeed, in a world where resources are finite, it is important to remember that every action requires energy and matter, including transforming, creating, storing, or exchanging information. Digital technologies are no exception: they are not virtual tools, but rather physical systems and media, although we do not always directly perceive their materiality.

Digital technologies form a global system: terminals (smartphones, computers, tablets, etc.) connect to each other via network infrastructures (terrestrial and submarine cables, mobile network antennas, optical fibers, etc.) in order to exchange information stored and processed in data centers, the beating heart of this system. However, each of these elements requires energy not only to operate (use phase) but also, before that, to be built (production phase): mining and refining of raw materials, industrial transformation and manufacturing processes, then delivery to consumers: the entire life cycle of these elements requires biotic and abiotic resources.

Every digital service relies on physical infrastructure whose resilience and relevance to the double carbon constraint (reducing carbon emissions from our activities; freeing ourselves from our dependence on fossil fuels) must be questioned. Digital technology is a catalyst: wherever it is deployed, it allows for optimization, acceleration, streamlining, parallelization, etc. Artificial intelligence is one of these tools, and generative AI adds new layers of uses.

Deploying all these systems without a long-term strategy that integrates the double carbon constraint leads to the acceleration of all current dynamics, including those furthest removed from our resilience objectives. Making digital technology a true tool for reinventing our activities to make them compatible with planetary boundaries requires a systemic consideration of the impacts of digital technology.

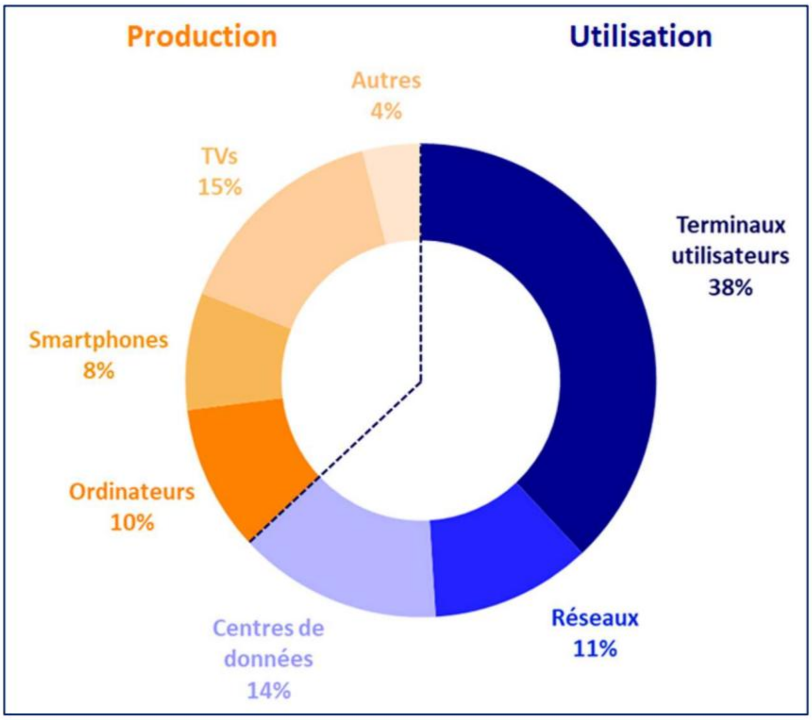

Figure 1 - Distribution of the global digital carbon footprint in 2019, by function for the production (40%) and use (60%) phases. Source: (The Shift Project, 2021)

II. An unsustainable trajectory that must be reversed

Digital technology already accounts for nearly 4% of global emissions (The Shift Project, 2021), the same as all heavy-duty vehicles worldwide (IEA, 2021a).
On a French scale, it represents 4.4% of the country's carbon footprint[1] (ADEME, 2025).

The particularity of the digital sector lies in the rapid increase in its emissions, which are growing according to a trend particularly incompatible with its decarbonization: + 6%/year on average at the global level (The Shift Project, 2021) and + 2 to 4%/year in France (ADEME & Arcep, 2023; HCC, 2020; Sénat, 2020). Technical and operational optimizations are not enough to compensate for the sustained deployment of its infrastructures, parks and flows (ADEME & Arcep, 2023; Bol et al., 2020; European Commission, 2020; GreenIT.fr, 2019; IEA, 2022, 2024a; LBNL et al., 2024; The Shift Project, 2023). This observation continues to be verified and has been illustrated over the last five years, which according to certain studies were expected to mark a leveling off of these impacts thanks to technological progress (IEA, 2019; ITU-T, 2020; Masanet E. et al., 2020). Large-scale deployments of AI and its component

[1] Data for the year 2022

generative could worsen these already unsustainable dynamics. This report therefore aims to shed light on them.

On a French and global scale, digital technology will represent around 10% of total electricity consumption in 2022 (ADEME, 2025; The Shift Project, 2021, 2023), a significant share that should earn it the same level of attention as other sectors. In a context of intense electrification of uses (mobility, buildings, industry, etc.), we understand that it is also at the heart of the challenges of planning the transformation of our systems and prioritizing access to resources that are now in tension, including electricity (The Shift Project, 2023b).

Making digital compatible with the double carbon constraint therefore involves not only strengthening optimization levers already deployed, but placing it on a fundamentally different trajectory from the one it is currently following. Like other sectors of the economy, it must achieve its decarbonization objective, which industrial players (GSMA, GeSI[2]) have themselves set through the SBTi initiative and on the basis of an ITU recommendation (SBTi et al., 2020) (p. 9) of -45% in 2030 compared to 2020 at the global level[3] .

The Shift Project proposes to use this objective as the basis for constructing the national trajectory, adapting it to the specificities of the already significant decarbonization of the country's electricity mix. The Shift Project recommends building the French trajectory around this recalculated SBTi objective to adapt it to the French case, of -30% of the sector's emissions by 2030 compared to 2020 (The Shift Project, 2023).

The construction of our digital system is done through multiple interactions between the technical system and the uses it underpins. Analysis of energy and climate issues using a systemic approach highlights that controlling the impacts of digital technologies requires in-depth consideration of the deployment of offers, the adoption of uses that we favor or not, as well as the place of sobriety. The mobilization of sobriety levers (inflection of the volumes of terminals, data and calculations) is even one of the sine qua non conditions for controlling energy consumption thanks to energy efficiency gains (The Shift Project, 2023).

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[2] GSMA: GSM Association, an association bringing together international players in mobile connectivity (manufacturers, operators, etc.). | GeSI: Global Enabling Sustainability Initiative, a group of international players in the digital and telecommunications sectors, whose mission is to work on sustainable digital technology.

[3] A framework of non-quantitative commitments exists at the national level, made by French manufacturers as part of the decarbonization roadmaps for the digital sector.

III. Why work on the energy-climate footprint of artificial intelligence and the development of computing capabilities?

On November 30, 2022, generative artificial intelligence made a dramatic entrance into the public debate with the release of the ChatGPT conversational agent. Adoption was dazzling: 1 million users in 5 days, 100 million in 2 months (Sagot B., 2023), with 400 million weekly visits (L'usine digitale & Seramour C., 2025).

Since then, the new uses enabled by generative artificial intelligence4 have developed a digital system and, more broadly, an economy that is already subject to the double carbon constraint. Like other online platforms and search engines targeting the general public, ChatGPT is based on a volume strategy aimed at widespread adoption, but is distinguished by a much higher computing intensity both upstream (in the construction of the service) and downstream (in the use of the service). This automatically leads to a higher marginal environmental cost: the mass adoption of a service that is computationally intensive significantly amplifies the pressure on electrical resources and the environment.

This consumer-grade generative artificial intelligence is the result of:

- **Academic research and R&D in the field of automatic language processing (and its integration into a "direct" and "natural" human-machine interaction interface),**
- **Technological strategies for increasing the power of processors and graphics processors, • Delegating**

storage and computing capacities to high-performance infrastructures economies of scale effects (cloud),

- **The development and accessibility of large corpora of texts, often enriched with linguistic annotations enabled by the collection and storage of data.**

These dynamics, specific to generative artificial intelligence, are integrated into a systemic logic: digital technology operates as a system and its three tiers (terminals, network infrastructures, data centers) evolve in concert, made interdependent by data exchanges. The deployment choices made at the level of data uses and infrastructures impact the entire digital system while being the result of the general trajectory given to the system (Figure 2):

- **The desire to develop the new uses promised by the "generative AI" moment justifies the deployment of new technical capacities (improvement of processor capacities, increase in server bay capacities, deployment of data centers to achieve the necessary computing and storage capacities, etc.): this is the effect**

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[4] See paragraph "AI and generative AI: a technological breakthrough?"

of use; ;

- The deployment of new technical capabilities leads to the development of new uses (possibility of having rapid and simple access to a response or an image produced thanks to very significant computing capabilities, etc.): this is the supply effect.

Uses and infrastructure remain two sides of the same coin. What is perhaps unique about this "generative AI" moment is the speed with which the loop is activated: financial, human, and technical investments are being mobilized in considerable amounts, both to fuel the massive deployment of data centers and to catalyze the adoption of the uses then made possible, thus justifying the continuation of the dynamics.

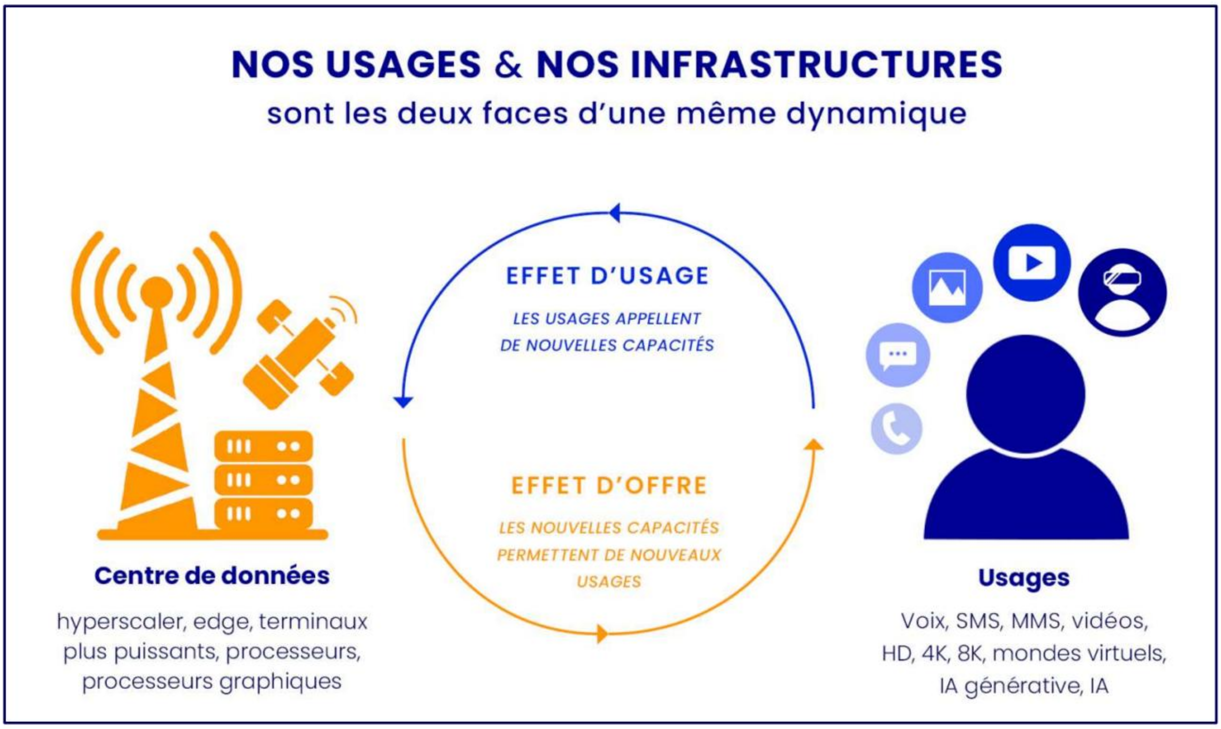

Figure 2 - Our uses and our networks are two sides of the same dynamic.
Source: Interim Report, The Shift Project, as part of this report

This report aims to study the dynamics structuring data uses (computing and storage infrastructures, dynamics of deployment of applications that are intensive in computing resources, etc.) with particular attention to the modifications of the digital system induced by the new uses of generative artificial intelligence and its constituent technological and infrastructural bricks (new processors, replacement of servers, new data centers and new types, accelerated replacement of obsolete equipment for AI, terminals with more computing power, etc.).

The areas of work are as follows:

- What trends are the energy-carbon footprint of data centers evolving on a global scale? Is the recent amplification of digital dynamics with the “AI phenomenon” (on data centers, terminals and networks) delaying the possibility of reversing the trends in greenhouse gas emissions from the digital system, which is essential to achieving the sector’s objectives (SBTi et al., 2020) (p9)?

- What are the implications for demand and the electricity sector? What are the issues to be integrated into strategic thinking at the French and European levels?
- How can AI, and more broadly the increase in computing capacity, be placed on a trajectory compatible with physical constraints? What choices need to be made to make them relevant in their contribution to the decarbonization of the digital sector and that of other sectors?

IV. Data centers: today a difficult-to-observe observable, tomorrow a management indicator

While the effects of the broad deployment of (generative) artificial intelligence and its dynamics extend far beyond the single third of "data centers," leading to a distortion and inflation of the digital system as a whole, data centers are today a central element of this new digital dynamic.

Their energy consumption has been estimated several times in the past but is not monitored in real time. On a global scale, the jump from 200 TWh to 460 TWh between the two IEA publications (IEA, 2021b, 2024a) or between those of Masanet and LBNL (LBNL et al., 2024; Masanet E. et al., 2020) is indicative of this difficulty in measuring and forecasting energy consumption over a 3 to 5 year timescale. Similarly, at the national level, the works "Energy Futures 2050", "Forecast Report 2035", "Ten-Year Network Development Plan 2040" (RTE, 2022, 2023, 2024) make ad hoc estimates but the absence of a public inventory of data center projects in progress is worrying, all the more so given the change in scale announced at the Summit for Action on Artificial Intelligence held in 2025 in Paris[5] . The on-board carbon footprint of data centers remains a blind spot in analyses and projections, as do local issues such as the use of water resources and land artificialization. Establishing inventories of data center projects to track their locations, energy consumption and greenhouse gas emissions is increasingly essential but is currently lacking for transition scenarios.

Making greenhouse gas emissions from data centers over their entire life cycle an indicator for steering dedicated public policies would ensure that the rates of energy efficiency, carbon intensity and demand are compatible with the trajectories and reference objectives of the sector and the territory.

In addition to the risks of resilience and sovereignty posed by digital technology, and AI in particular, these dynamics include those of endangering the energy-climate transition and of weakening

[5] At the Summit for Action on Artificial Intelligence in France on February 10-11, 2025 (Elysée, 2025), announcements of large-scale data centers were made: 1 GW on an AI-focused campus (Le Monde, 2025a) and 1 GW in Cambrai (Le Monde, 2025b). This places some data centers on the same level as some large-scale industries, as illustrated by the IEA: data centers are more spatially concentrated than steel plants, coal and ore mines, power plants, and warehouses (fig. 4.12 in (IEA, 2024b)). This change in the scale of computing power from the tertiary sector to the industrial sector is a phenomenon that must be acknowledged in order to propose appropriate policies (Carnino G. & Marquet C., 2022), particularly climate policies.

electricity transmission networks, both globally and in France. The case of Ireland and the decisions to use fossil fuels in the United States to power data centers, which we will return to later in this report, are particularly illustrative of these issues. Similarly, other environmental criteria should be monitored at the local or even national level, especially since there are certain regulations concerning them. To cite three of them: artificialization of soils due to the construction of

new data centers, to be monitored under the ZAN[6] law of July 20, 2023; the preservation of natural environments and biodiversity[7] monitored, for example, under the law for the recovery of biodiversity, nature and landscapes; water withdrawals and consumption regulated by the Water Framework Directive.

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[6] Zero net artificialization Data

[7] center construction may require the clearing of woodlands hosting various protected species. See for example https://www.mrae.developpement-durable.gouv.fr/IMG/pdf/2023-08-09_marcoussis_91__projet_extension_data_center4_avis_delibere_.pdf.

What developments in global computing capabilities are due to the “generative AI phenomenon”?

This question comes at a time when artificial intelligence (AI) and in particular generative artificial intelligence (GenAI) are being invoked by major digital players to justify the poor direction of their climate trajectories (Google, 2024; Microsoft, 2024), which appear to be drastically deviating from the objectives they announced a few years ago. Similarly, artificial intelligence is the watchword chosen to justify the rapid deployment of data centers today and for the next ten years[8] with:

- On a French scale, the proposal of 1 GW for generative AI within 10 years (France Datacenter & EY Parthenon, 2024), made obsolete after the Summit for Action on Artificial Intelligence (Elysée, 2025) during which the following announcements were made: 1 GW on an AI-focused campus (Le Monde, 2025a), 1 GW in Cambrai (Le Monde, 2025b), 1 third GW (L'usine digitale, 2025) and 35 data centers totaling 1,200 hectares (DCMag, 2025a) (see figure 18),
- On a European scale, the deployment of 35 GW by 2030 (McKinsey & Company, 2024),
- On a global scale, the deployment of 96 GW by 2026, including at least between 1.5 and 3 GW for each GAFAM increase in installed IT power (Schroders, 2024).

A somewhat simplistic statement would be to say that the development of data centers only responds to the demand for AI and GenAI, we complete this statement in order to extract the dynamics of the development of data centers:

- On the one hand, the offer is growing: computing capacities (whether in data centers or in terminals) are growing (Epoch AI, nd-b). The hardware configuration of data centers previously primarily (and on average) responded to the need for data storage, while the use of generative AI and other processing-intensive applications requires a very significant increase in computing capacities.
- On the other hand, we must be aware that setting up a data center takes 3 to 5 years (DCByte, 2024), that players are basing their decisions on anticipations and are not simply reacting to real and instantaneous demand to make investments that they will be keen to make profitable in the future.

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[8] The following figures are first orders of magnitude of what is being said in terms of announcements and projections. The following sections will aim to shed light on the readability (or not) of these figures.

- Some key players do not even explain the development of data centers through generative AI, but rather choose to highlight the commitment to digital that was created during the COVID-19 pandemic as well as the development of the cloud (DCByte, 2024).
- Finally, it is not impossible that we are facing a period of overinvestment, with the players in the sector themselves announcing that it is above all a question of anticipating future growth, imagined to be gigantic but by definition uncertain[9] .

To shed light on the question of "what is the impact of generative AI alone?" and its attributionality (what is the current share of the climate footprint attributable to generative AI if we distributed the infrastructure over uses), bottom-up calculations based on a number of GPUs delivered (de Vries A., 2023) are interesting: they highlight the footprint linked to the manufacturing of the equipment and they help raise awareness of the environmental impact of generative However, they may not tell us enough about global structural dynamics to understand and anticipate them.

Ultimately, whether generative artificial intelligence is the inflationary factor or not, it is above all the symbol of the continuity of the extension of the digital system towards more computing power and it has a media aura (possibly by representing economic and geopolitical issues deemed sufficiently compelling) which avoids having to justify this expansion, even if it means jeopardizing climate commitments.

This section will therefore aim to address the climate footprint of this expansion around data centers but more broadly what relates to storage and computing (and therefore also terminals and networks).

> At the stage of publishing this interim report, we would like to encourage discussion and feedback, preferably constructive. We also want to encourage discussion on the assumptions and data considered in energy consumption forecasts, which are often overlooked even though they can have a significant impact on the results. All your comments, criticisms, and suggestions on the assumptions and data considered in energy consumption forecasts (which are often overlooked even though they can have a significant impact on the results), as well as any data research or interviews to be conducted, will therefore be a key ingredient for the continuation of this work!

I. Lessons from the past

Globally, until 2021, the IEA estimated data center electricity consumption of around 200 TWh (IEA, 2021b) and almost stable despite the sharp increase in uses.

[9] For example, the statements of Sundar Pichai (CEO of Alphabet, Google's parent company), "The risk of underinvesting in AI is terribly greater than the risk of overinvesting", or of Mark Zuckeberg (CEO of Meta), "[AI] is about building capacity before we need it, rather than too late" (Challenges, 2024).

Faced with the crucial lack of monitoring and reporting of information (no system for monitoring the evolution of the actual electricity consumption of data centers, for example), the only points of reference have long been the estimates and models carried out as part of academic work, the conclusions of which have sometimes had to be used at the periphery or even outside their scope of validity.

In 2020, the work of Masanet et al. had emphasized the energy efficiency gains that should not be underestimated, the basis of the statement that accompanied the IEA publications until 2021: "if current trends in data center hardware and infrastructure efficiency can be maintained, global data center energy demand can remain almost stable until 2022, despite a 60% increase in demand for services" (IEA, 2021b; Masanet E. et al., 2020).

In 2022, the IEA projects a range of 240 to 340 TWh (IEA, 2022). In 2023, the EDNA begins to question whether demand is too high compared to efficiency gains (EDNA, Technology collaboration programme by IEA, 2023). In 2024, the IEA produces a figure of 460 TWh for the year 2022 (IEA, 2024a).

The lack of monitoring of the evolution of data centers in recent years and the
Excessive confidence in the potential for efficiency gains seems to have hampered any preparation regarding electricity production for these players, the management of electricity transmission networks as well as any vision for regulating greenhouse gas emissions (a sector not included in the EU-ETS emissions permit market, for example). This lack of preparation is felt in a digital sector with particularly intense dynamics.

It would be valuable for public and international action to trace the actual history of the deployment of data centers and to evaluate the decisions taken as a result.
This is what the LBNL publication begins by looking back at the history of past estimates (Figure 3, (LBNL et al., 2024)). To this history of estimates could be added the Borderstep estimate which, as early as 2020, anticipated this development: 350 TWh in 2017, 500 TWh in 2022 up to 880 TWh in 2030 (Hintemann R. & Hinterholzer S., 2020). The Shift Project published, in 2021, 4 descriptive scenarios of different trends in usage and efficiency: starting from 420 TWh of final energy consumption in 2019, evolving towards 370 TWh to 549 TWh in 2022, and towards 331 TWh to 734 TWh in 2025 (The Shift Project, 2021).

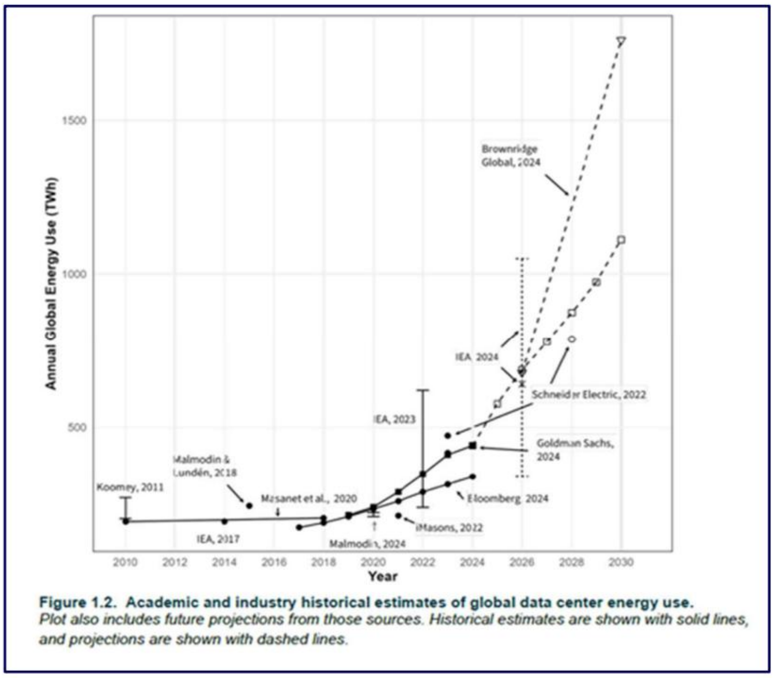

Figure 3 - Historical estimates of global data center electricity consumption between 2020 and 2030 (vertical scale starting at 100 TWh for the left graph). Source: (LBNL et al., 2024)

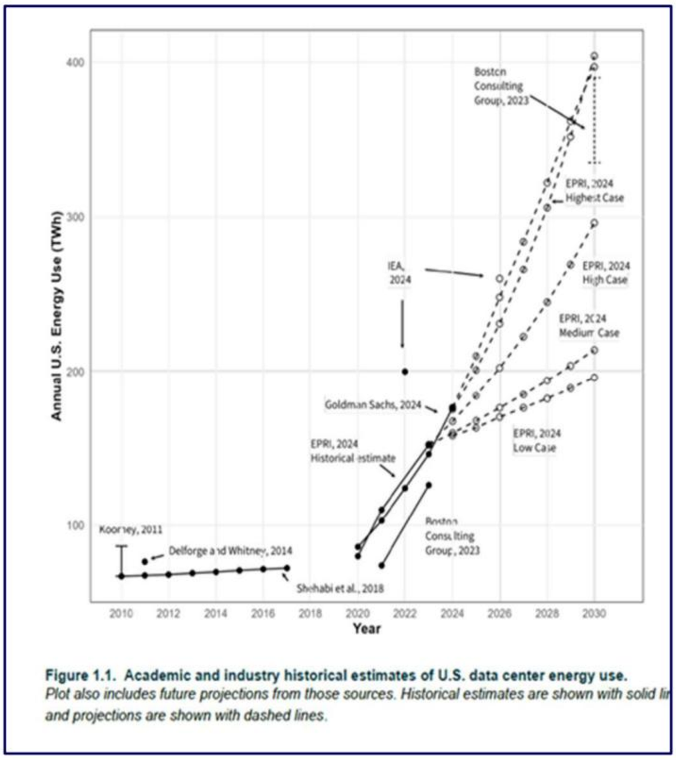

Figure 4 - Historical estimates of data center electricity consumption between 2020 and 2030 in the United States Source: (LBNL et al., 2024)

LBNL also traces the historical growth in the United States: a doubling between 2014 and the end of 2021, the date of the introduction of consumer generative artificial intelligence (figure 4).

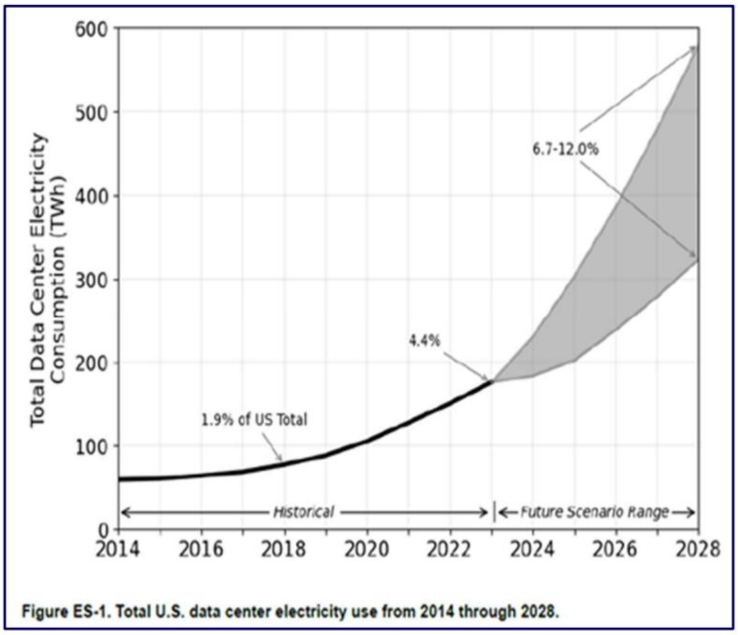

Figure 5 - Historical data center electricity consumption between 2014 and 2023 in the United States.
Source: LBNL, 2024

On a global scale, this initial reflection on previous estimates can also be enriched by data center capacity surveys: DCByte data being in demand for electrical power for IT and Jefferies data in demand for total electrical power for data centers (Figure 6). These data highlight the constant growth in capacity deployment between 2018 and 2023, and the acceleration since 2023 (even more visible in Figure 7).

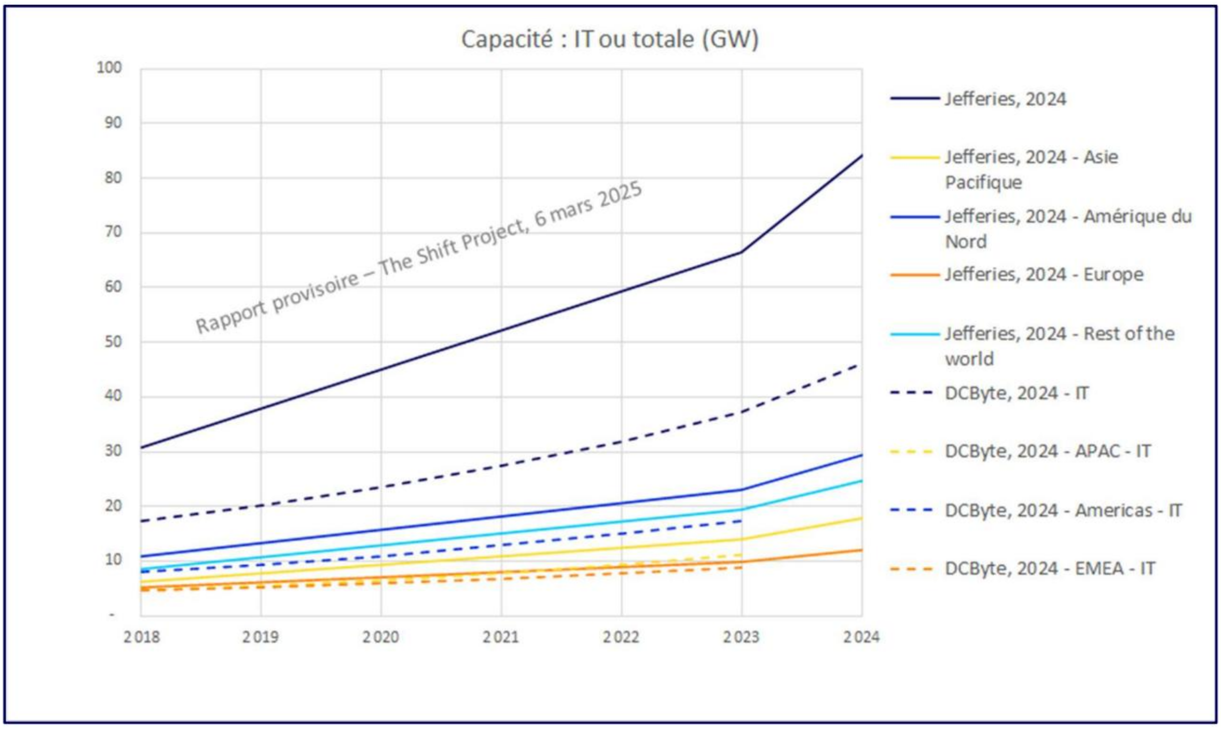

Figure 6 - Electric power: historical 2018 - 2023. Sources: (DCByte, 2024; Jefferies, 2024)

In view of digital dynamics, this must now accelerate the implementation of systems for monitoring data centers, their electricity consumption and their greenhouse gas emissions over their entire life cycle. The EED, by requiring reporting for data centers of more than 500 kW in a European database, is a starting point in this sense (Official Journal of the European Union, 2024).

II. The state of current trends in the sector

A. Inventory

The two graphs below bring together various projections of data center electricity consumption (TWh) and computing capacity (GW) produced by: energy players, analysts from strategy consulting firms (general or specialized in the data center sector), R&D laboratories, academics and investment banks.

Two cautions when reading these graphs: the first concerns the description of the hypotheses in the reports consulted, which is far too minimal given the importance of the subject; the second concerns the scopes, which may vary depending on the studies. These are two blind spots that will need to be addressed in future global assessments:

• Until now, many projections do not include all types of data centers and focus only on the largest: hyperscalers, cloud, colocation (see "Appendix 1: Data center typology"). Own-source data centers are still too often forgotten even though they can represent 5% to 50 %10 of electricity consumption depending on the geographical area and year considered. In addition, "edge" type data centers could be more numerous in the future, or even computing power could be much more decentralized (see "What impacts on terminals and networks?") if our digital system evolves towards a layered model where processing power is more distributed11 . • Until now, reports have focused on only 3 large areas: United States, China, and Europe. But in 2023, there were already 2.1 GW of installed IT power for the South East Asia12 zone (BCG, 2024) and 11 GW for the Asia Pacific13 zone (DCByte, 2024) with 1.2 GW of projects operational or in progress in Mumbai. In Brazil too, São Paolo already has 0.7 GW of installed IT power and announcements are being made for a project of up to 5 GW (Data Center Dynamics, 2024c).

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[10] Depending on the geographical areas and time periods. For example: 5% projected at the global level in 2028 (LBNL et al., 2024), 23% projected in Europe in 2028 (McKinsey & Company, 2024), 35% at the global level in 2018 (Masanet E. et al., 2020), 50% for the French territorial count in 2020 (ADEME & Arcep, 2023)

[11] This topic is all the more important to consider as these data centers could be less powerful and less efficient than central data centers due to more limited sharing.

[12] Singapore, Malaysia (Johor), Indonesia (Batam), Thailand, Philippines, Vietnam

[13] South East Asia + India, Australia, New Zealand, Japan, South Korea + Hong Kong, Taiwan

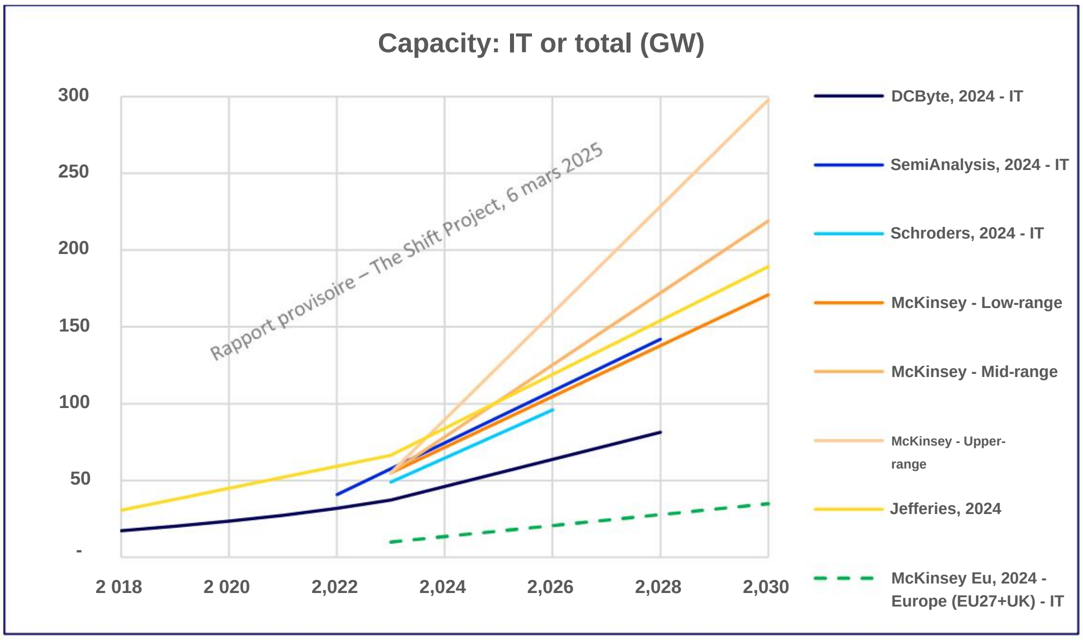

Figure 7 - State of play of IT or data center electrical power demand forecasts in global data centers. Sources: (DCByte, 2024; Jefferies, 2024; McKinsey & Company, 2024; McKinsey, 2024; Schroders, 2024; SemiAnalysis et al., 2024)

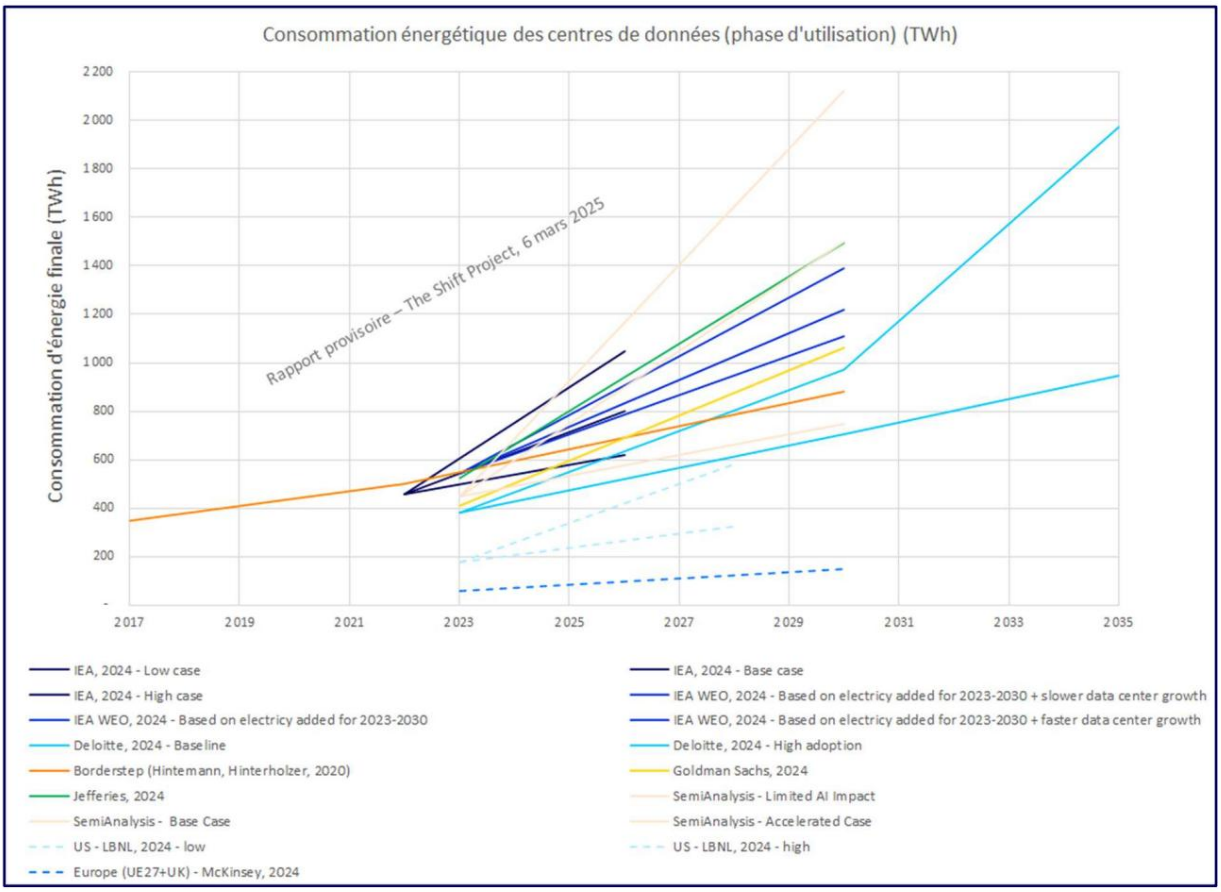

Figure 8 - Status of annual electricity consumption forecasts for global data centers. Sources: (Deloitte, 2024; Goldman Sachs, 2024; Hintemann R. & Hinterholzer S., 2020; IEA, 2024a, 2024b; Jefferies, 2024; LBNL et al., 2024; McKinsey & Company, 2024; SemiAnalysis et al., 2024)

What conclusions?

- The status quo that prevailed until 2021 of an almost constant annual global electricity consumption of data centers around 200 TWh is definitely obsolete.

- DCByte forecasts 89 GW of operational IT power in 2028, where Jefferies estimates 189 GW for data centers in 2030.
- In energy consumption, current projections for 2030 vary from 700 TWh to 2,100 TWh in 2030, which shows significant uncertainties, which all stakeholders note. The IEA scenarios in its "WEO report 2024" range from approximately 1,100 TWh to 1,400 TWh, while those indicated in the "Electricity report 2024 to 2026" lead (by extending to 2030 the trends indicated up to 2026) to 840 TWh - 1,400 TWh - 2,400 TWh depending on the case.

- The majority of projections are in electricity consumption (TWh) or installed power (GW) which does not reflect the type of electricity used or the carbon footprint, two critical elements since: o Some data centers (many in the United States) have announced that they will use gas or coal,
  implying that power plants will not be closed as normally planned, which results in at least a factor of 10 on the electricity emission factor (see end of the paragraph "Global IT and energy dynamics: the example of the United States").

  o Until now, the on-board carbon footprint could represent between 1/314 of the carbon footprint linked to electricity consumption and as much as 15 (depending on the type of electricity). In addition, replacement rates could evolve (possibly towards more efficient servers) (little data available to date on this subject).

- Until now, the annual electricity consumption of data centers has already increased at a rate of more than doubling in ten years, due to the development of digital uses and despite the energy efficiency gains resulting from the transition to the cloud.

The current deployment of generative AI exacerbates this trend by 2030 by inducing a sequence of massive investments on all continents, the necessary profitability of which could lead to a tripling of consumption in eight years (based on the IEA's high vision in IEA WEO, resulting in a consumption of 1391 TWh).

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[14] In the study (Schneider Electric, 2023): for the United States case, the "Scope 3 on-board footprint" represents 35% of Scope 2; for the case of France, the "Scope 3 on-board footprint" represents 104% of Scope 2. The values are taken at 15 years of lifespan for a data center defined in the introduction to the report.
[15] The same applies when taking an electricity emission factor representative of France.

B. Evaluation of electricity consumption and perspective

This part is one of the major areas of work remaining to be continued following this interim report.

This work will aim to:

• Produce transparent prospective modeling of the evolution of consumption electrical of data centers; • Put into perspective the results produced in the literature (see previous section); • Highlight the factors and variables on which the final results depend first order, in order to clarify the comparison of the different estimates.

The first elements of analysis resulting from the start of this work are as follows:

• There is currently a very significant variability in the results (which can be up to a factor of 2 over a 5-year horizon), given the lack of consolidation of certain key data and the sensitivity of certain assumptions; • The structure of the modeling tool is available in "Appendix 3: Carrying out and/or interpreting an estimate of the electricity consumption of data centers: what questions to ask?" and a complementary resource (spreadsheet) for this report.

One of the crucial objectives of the follow-up to this work will therefore be to collect, critique and consolidate the values of the key modeling parameters, in order to build a transparent overview. All your comments, critiques, suggestions on the current content or structure of the modeling, as well as any research/data acquisition leads will therefore be a key ingredient for the follow-up to this work!

III. What is the carbon footprint of global data centers?

This calculation aims to translate the trajectories followed by data centers into greenhouse gas emissions, including: greenhouse gas emissions from energy consumption and the on-board footprint linked to the production phase.

Three points were looked at:

- **The year 2022 based on the consumption of 460 TWh (IEA, 2024a), •**
The year 2030 with two consumptions of 1220 TWh and 1390 TWh to take into account the reference case and the rapid growth case (IEA, 2024b).

With two assumptions of electricity carbon intensity factor:

- **The factor evolves from 460 gCO2e/kWh in 2022 to 312 gCO2e/kWh in 2030 (IEA, 2024b) (Stated Policies, p301),**
- **The factor remains at 460 gCO2e/kWh to model a data center addition of which all new demand would be met only by gas16 .**

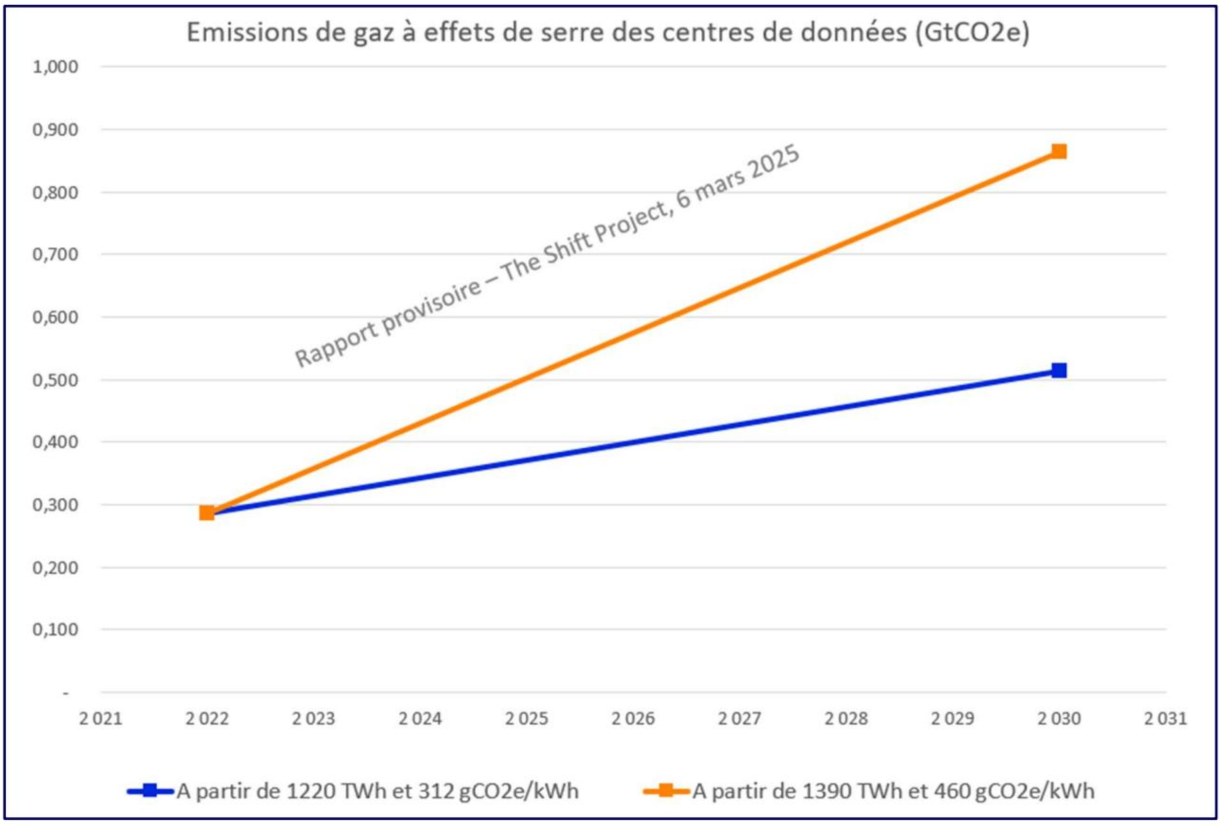

Figure 9 - Translation of several estimates into greenhouse gas emissions (GtCO2e) . Source: Interim report, The Shift Project, as part of this report

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[16] Whose emission factor is approximately 450 gCO2e/kWh.

Between 2022 and 2030, greenhouse gas emissions would increase to between 514 and 864 MtCO2e, an increase of 80% and 200%.

In 5 years, by 2030, current choices for building data centers worldwide could result in greenhouse gas emissions of around 0.86 GtCO2e, which represents:

- **More than 3/4 of CO2 emissions from the civil commercial aviation sector alone[17] ,**
- **1.6% to 2.0% of emissions in 2030, for data centers alone, depending on the comparison scenarios[18] .**

This calculation is based on projections (described in the previous paragraph), which we recall may have their limits: both in terms of efficiency gains, but also in terms of availability (energy, including low-carbon, material, financial, supply actually meeting demand).

Following this interim report, to improve these carbon footprint projections, work could be carried out on scenarios for electricity consumption, taking into account different possible trajectories for carbon intensity, energy efficiency, and supply and demand.

The calculation is detailed in "Appendix 2: A first calculation: "What carbon footprint for global data center projects?"", please contact us for any technical exchange or regarding additional data that you could provide us. All your comments, criticisms, proposals on the directions explored at this stage, as well as any research/data acquisition leads will therefore be a key ingredient for the continuation of this work!

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[17] Summary of the Power to Fly in 2050, p2, 1.1 GtCO2e in 2018 (The Shift Project & Supaero Decarbo, 2021)

[18] Compared to 54 GtCO2eq in 2030 by limiting warming to 3°C (>50%), Table SPM.2 (Intergovernmental Panel On Climate Change (Ipcc), 2023), we obtain 1.6%.
If we compare this to 44 GtCO2eq in 2030 (limiting warming to 2°C (>67%), Table SPM. 2 (Intergovernmental Panel On Climate Change (Ipcc), 2023), we get 2.0%. The compatibility between these scenarios on data centers and a 2°C trajectory (>67%) on a global scale is more than questionable, since this "surprise increase" of 0.86 GtCO2e is not compensated by consideration in the scenarios of other sectors.

IV. Global IT and Energy Dynamics: The Example of the United States

At the heart of these dynamics is the growing investment in data centers in the United States, the significant reduction in the cost of graphics processors, as well as the recent and drastic increase in the size of artificial intelligence models (Figure 10).

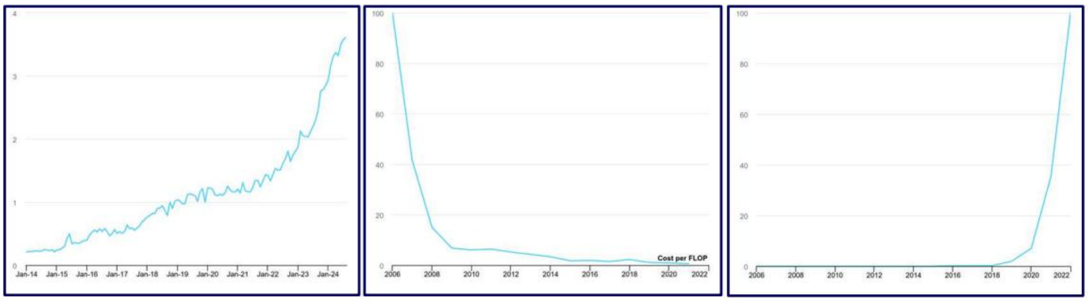

Figure 10 - Investments in data centers in the United States (left)[19], cost of graphics processors (center)[20], size and complexity of artificial intelligence models (right)[21]. Source: (IEA & IEA Paris, 2024c, 2024b, 2024a)

On the machine learning side, according to the Epoch AI website, we are seeing an increase in hardware and algorithmic performance (at iso-usage), an increase in model performance and an increase in the computing power required to train "remarkable" machine learning models (Epoch AI, nd-b).

On the graphics processor side, the power of graphics processors, evaluated according to their TDP[22], was around 250 W 2-3 years ago, is now around 1 kW, and could increase further[23] within 2 years.

For a fixed fleet, this therefore implies an increase in electricity consumption as well as an accelerated replacement of less powerful equipment (this equipment can be resold and used in another fleet or not).

Power densities are therefore increasing, at the server level as well as at the data center level, which can make the structures unsuitable, in terms of cooling as well as capacity.

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[19] Y-axis index worth 1 in December 2019.

[20] Cost per flop index in ordinate value 100 in 2006. Notes: FLOP = Floating Point Operations.

[21] Flop index worth 100 as of December 2019. Notes: The underlying data refers to the Training Compute (FLOP).

[22] Thermal design power, namely the heat transfer to the outside that this component must be able to benefit from in order to function properly.

[23] From the Thermal Design Power (TDP), making the approximation that they are close to the energy consumption (hypothesis which can hold if the hardware operates at its maximum capacity), 300W for the A100 (A100, sd), 700W of TDP for the H100 (H100, sd), 2700W for the GB200 Superchip (GB200 Superchip, sd) (if we consider that it is a single chip).

While Epoch AI is unsure of the 20-year trend, it believes there may be an increase in TDP for the latest ML GPUs (Epoch AI, nd-c).

power supply, so much so that the Uptime Institute already reports that 29% of data center operators are upgrading their rooms[24] (Uptime Intelligence, 2024)[25] .

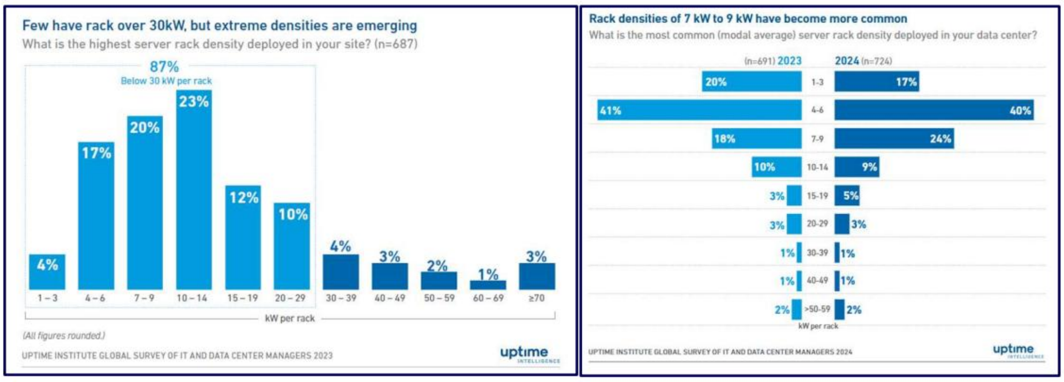

Figure 11 - Increasing power densities in data centers. Source: (Uptime Intelligence, 2023, 2024)

Finally, if we couple this with an increase in uses (enabled by availability of the offer): model training, “individual” or “office” uses (including constantly increasing inferences (L'usine digitale & Seramour C., 2025)), other very intense services favored in the Uptime Intelligence survey (Figure 12), this leads to an increase in the load on data centers; these being built in advance so that the services are always available.

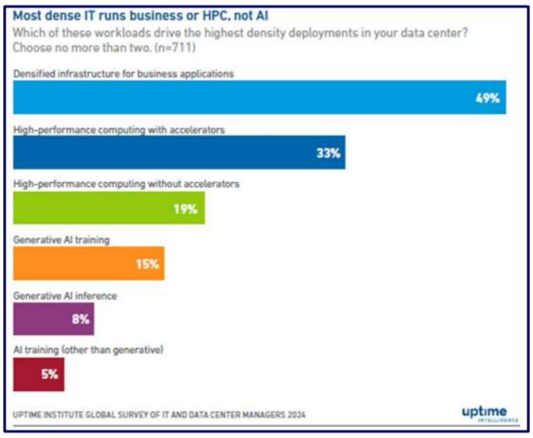

Figure 12 – Uptime Intelligence survey on “dense” applications. Source: (Uptime Intelligence, 2024)

[24] In the ultimate case, the entire data center will have to be replaced, which will likely result in the construction of a new data center, while the existing one is retained to provide lower value-added services.

[25] The methods used by Uptime Intelligence are email surveys to 850 data center owners and 750 vendors and consultants, see last figure of their report for more information.

In terms of energy efficiency gains at the data center level, we see an improvement in PUE[26] with an average of around 1.55[27] (Figure 13).

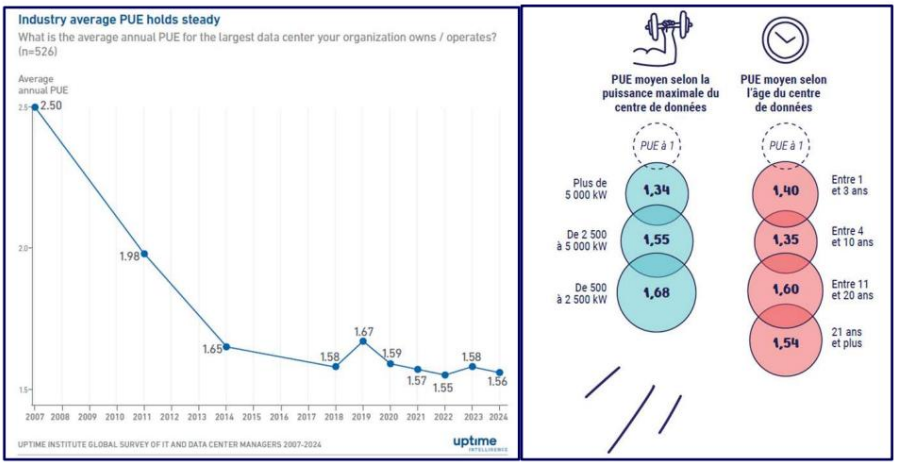

Figure 13 - Evolution of PUE. Sources: (Arcep, 2023; Uptime Intelligence, 2024)

On the energy side, the installation of these new data centers imposes new electricity consumption requirements. But in the United States, an energy wall with carbon consequences has been looming since early 2024:

- **AI, cloud computing and cryptocurrencies, via data centers, are exerting strong and unforeseen constraints on electricity transmission networks aging, transport networks that are already growing to accommodate electrification of uses and reindustrialization (Washington Post, 2024).**
- **Faced with these energy difficulties, major players are looking for low-carbon electricity production: Amazon has signed an agreement with Dominion to explore the deployment of 0.3 GW of SMR (Data Center Dynamics, 2024d), as is Oracle, which is seeking to equip a future data center with 3 modular nuclear reactors, and Microsoft is restarting the previously shut down nuclear power plant at Three Mile Island. Sam Altman, CEO of Open AI, is funding a nuclear fusion start-up: Helion Energy (Le Monde & Alexandre Piquard, 2024).**
- **But the energy needs for AI are immediate. While waiting for SMRs or nuclear fusion, players are turning to fossil fuels, particularly gas. This is the case of xAI's data center, Colossus, which has equipped itself with 35 MW of mobile natural gas generators (Data Center Dynamics, 2024b) and Meta, which announces three natural gas turbine power plants for a total of 2.3 GW (The Register & Brandon Vigliarolo, 2024).**
- **The US Southeastern electricity grids plan to add 20 GW of natural gas-fired power plants (which would imply 80 $MtCO_2e$ annually) (Data**

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[26] Power Usage Effectiveness: An indicator of energy efficiency used to assess the energy efficiency of a data center. It is the ratio between the total energy consumed by the entire operations center (including cooling, air handling, inverters, etc.) and the portion actually consumed by the IT systems that the center operates (servers, storage, network).

[27] Be careful not to extrapolate future gains from such a curve: (i) the PUE will not fall below 1, which limits the efficiency deposit, (ii) concerning PUE, it should be noted that PUE in nominal use are very different from PUE during the data center filling phase (we will discuss this again below, like any efficiency indicator, it is degraded when the volume is low).

Center Dynamics, 2025) and First Energy cancelled the closure of two coal-fired power plants, keeping them open until 2035-2040 (Financial Times, 2024).

To avoid this continuation of fossil fuels, the keys are in the hands of the information and communication technology sector.

Ultimately, the extent of the effects of these different dynamics will depend on:

- Supply and demand: the extent of development of AI supply and its adoption (inferences but also volumes and intensities of training), the growth rate and intensity of digital uses in general, financial availability and investments, processor production and supply chains.

- Energy efficiency of the digital system: from the development and adoption of more efficient or even frugal models[28], from the development and adoption of more efficient processors with a reduced carbon footprint and from the management of data centers (cooling, reuse of fatal heat, optimized parks).
  - o But also the speed of renewal for digital equipment in data centers[29] .
  - o But also the development of the edge, namely data centers at most close to consumers[30] .
- Link between energy efficiency and supply: does efficiency serve a broader demand? Will a rebound effect result? (Luccioni AS et al., 2025) To the extent that computing power is made available, efficiency can lead to very large-scale dissemination even in use cases initially considered marginal or useless, which now have the possibility of being deployed (supply effect). • The carbon intensity of electricity: the availability of electrical power, in particular decarbonized.

These uncertainties are significant, not to mention those attributable to the fact that public data on these subjects are never complete (few sources, rarely explained hypotheses, no details on the models), and that manufacturers and suppliers are not transparent about energy and environmental data.

However, even in the lowest-risk scenarios, the evolution of digital technology, and particularly AI, is too rapid compared to the structural timescales for transforming electrical infrastructure and energy efficiency. This speed gap highlights the lack of accountability for these rates of change and the failure of a policy of non-regulation, marking a misalignment of decarbonization objectives between public and private actors.

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[28] (AFNOR, 2024): Note that this standard does not only contain good efficiency practices

[29] How premature hardware replacement impacts the system's energy and climate footprints digital? (Imprint embedded in additional manufacturing, but what second life for the equipment in question?)

[30] How does the edge affect the energy and climate footprints of the digital system? (Lightening the load on networks, but ege generally uses existing infrastructures, which are less energy efficient and larger. With lower latencies, because they are closer to the locations of data production or service consumption, it can be used for inference. With lower capacities, it can be used for retraining.

In the work that will follow this interim report, it will be a question of exchanging with the stakeholders of the sector to raise the questions that will have to be addressed by the actors, once a consolidated observation made by our work has been made: in addition to necessary transparency, what options are already explored or now to be considered to allow the alignment of objectives: rating mechanisms?

Market mechanisms and rules, price signals, emission permits? Incentives?
Penalty policies? How and based on what standards would these mechanisms be designed in order to act at the right level and on the right scale? All your comments, criticisms, proposals, or avenues for research/ interviews on the questions that stakeholders are asking and should ask themselves will therefore be a key ingredient for the continuation of this work!

V. What impacts on terminals and networks?

Generally speaking, although AI may in some cases replace other solutions, its deployment is in addition to the existing digital system.

Describing its impacts on terminals and networks can be done by adopting a "consequential" approach. Rather than attempting to assess the direct impacts of AI uses through the way they solicit infrastructures and supports, this type of approach consists of asking the question of the consequences of the introduction of services: what new dimensions and new technical characteristics of systems (terminals, networks and data centers) will be generated and motivated in the case of a given level of deployment of AI services in society and the economy? This approach has the advantage of questioning the subject from the angle of application deployments, services and uses (the usage effect), while linking them to the infrastructure projections that are supposed to enable them (the supply effect) (Figure 2 - Our uses and our networks are two sides of the same dynamic.

Source: Interim Report, The Shift Project, as part of this report (Figure 2).

In the same way that these works study the effects of the deployment of AI on the distribution of computing capacity (edge, centralized) or on the macroscopic sizing of data center infrastructures, the "consequential" approach makes it possible to bring out and clarify the possible effects on the capacities of terminals or the specifications of networks called for by AI in the medium and long term.

Consequential LCA

A consequential LCA (C-LCA) is a codified methodology whose objective is to model all the environmental impacts resulting from a change occurring in the life cycle of a product (Dandres, 2012)31. The objective is therefore significantly different from that of an attributional LCA (ACV-A), which consists of studying the life cycle of a product. While the A-LCA is carried out in a static state where the life cycle of the product does not evolve over time, the C-LCA is based on the evaluation of the consequences caused by the transition from state A to state B of the life cycle of a product. There is therefore a temporal notion to take into account in C-LCA

[31] https://publications.polymtl.ca/881/1/2012_ThomasDandres.pdf

corresponding to the period of time required for the product life cycle to move from state A to state B.

The approach of this report, which aims to shed light on the macroscopic dynamics of the components of the digital system, does not aim to produce a life cycle analysis, which aims to document the impacts of a functional unit defined according to precise specifications. What the work presented here integrates is the dynamic dimension in the study of the consequences of the trajectories chosen for a given system. The term "consequential" will therefore not be used in the sense of LCA-C in the remainder of this document.

What are the effects of AI on terminals?

Data centers are not the only storage and computing instances we consider in our analyses. The massive deployment of AI can indeed have consequences on terminals, which are linked to the rest of the digital ecosystem and its dynamics by phenomena such as the deployment of new architectures, the call for new capacities (data processing and storage) by emerging services or the associated obsolescence effects (software, functional, marketing, etc.).

Understanding these interactions makes it possible to identify the effects of supply and use (Figure 2 - Our uses and our networks are two sides of the same dynamic.
Source: Interim Report, The Shift Project, as part of this report Figure 2) affecting terminals, as well as the dynamics that result from them:

- Generally speaking, taking into account new needs for digital resources (memory and storage, processing capacities) to be able to provide local (at the terminal level) and disconnected AI services could lead to an increase in the environmental footprint of terminals, both in production and in use. The transition from the concept of IoT to that of Smart IoT and from thin edge to thick edge, for example, will generate a much higher energy and carbon intensity in the equipment manufacturing phase, through the use of more powerful processing and connectivity modules (Pirson T., Bol D., 2021).

-

- Energy efficiency gains (which therefore only concern the usage phase) at the terminal level could be offset by the renewal of the fleet due to obsolescence (caused by various factors: incompatibility with new software layers, triggering the act of purchasing a new terminal simply by the attractiveness of the services offered with it, etc.) and the impacts generated by the production of this equipment.

  new

- By usage effect, the anchoring of new AI applications in systems and usage habits as they are adopted can push for the deployment of new terminals specifically designed for AI. This will not only contribute directly to the increase in the fleet (and the associated environmental effects), but also to the penetration of AI services in uses (daily, industrial, institutional, multiplication of assistants and agents with high degrees of personalization and specialization, automation processes for complex tasks, etc.) which then become dependent on these new technologies, the high-level hardware and services that support them.

compose[32] .

• Potential economic rebound effects could then stimulate the supply of AI services, with the potential lowering of the costs of new AI terminals in the event of mass deployment making them more affordable.

In order to evaluate and project the induced effects of AI on terminals, the measurement (in FLOP, for example) of the processing capacity required by the different tasks called by the services could make it possible to:

• Quantify and monitor the risks and phenomena of obsolescence that would be generated by the deployment of a given service;

• Quantify and monitor the evolution of the intensity of AI services deployed or planned, prior to their adoption (a technological building block requiring more FLOPs will, for example, require either a more powerful terminal or longer calculation times);

• Measure the consequences of the fleet effect, i.e. the stagnation of available computing power in a given fleet. Stagnation not aligned with the growing theoretical capacity needs in the case of deployment of ever more intensive services, and due in particular to the extension, desired or imposed, of the lifespan of certain equipment[33]. Indeed , it is not guaranteed that there will be total substitution of old-generation terminals by AI terminals: contradictions exist between, on the one hand, the objectives of terminal durability and therefore of extending their lifespan and, on the other hand, the growing needs for computing power, particularly on terminals to run all or part of AI services (deployment of personal assistants in suites, for example).

of the office automation by

The large-scale deployment of AI-enabled terminals could therefore lead to a long-term intensification of computing resources for key or daily activities in our societies. The increase in data volumes produced and processed by terminals, which would result from this dynamic, would in turn affect network infrastructures, according to the same "supply effect - usage effect" logic.

[32] Note that it is not necessarily in the interest of service and hardware providers that local AI services be sober and frugal, i.e. that they can be run locally with simple and common terminals, not equipped for AI. Indeed, designed for AI, the terminals become inductors of the dynamics of increasing the need for AI services and the possibility of offering more of these services, once the terminals allowing them to be run are deployed.

[33] In 2021, ARCEP noted that the lifespan of smartphones had increased significantly between 2013 and 2019. More recently, the development of refurbished products and the proactive CSR policies of companies suggest that this trend is continuing (ARCEP, 2021: https://www.arcep.fr/actualites/actualites-et-communiques/detail/n/environnement-120721.html).

What are the effects of AI on networks?

Globally, network traffic is growing, both among consumers and businesses, driven primarily by video streaming. For example, mobile traffic increased by 30% per year from 2020 to 2024, rising from 55 eB to 157 eB per month (Ericsson, 2025).

In the future, some projections estimate, for example, for 2033, 3 scenarios (moderate, aggressive, disruptive) multiplying global traffic between 5 and 935 (Nokia, 2024). This evolution would be justified with the following breakdown of uses: video and social networks remain predominant for mobile uses, while business applications, XR and IOT share business traffic which would be multiplied by a factor of 8 to 21.

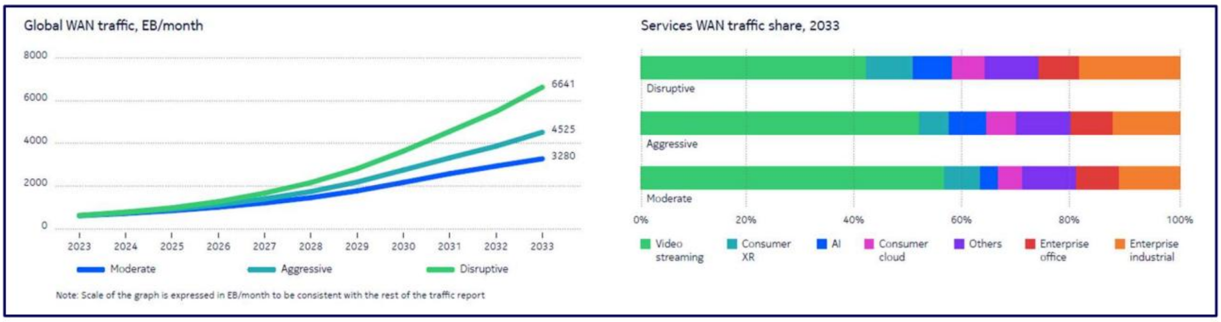

Figure 14 - Projections of internet traffic and usage to 2033. Source: (Nokia, 2024)

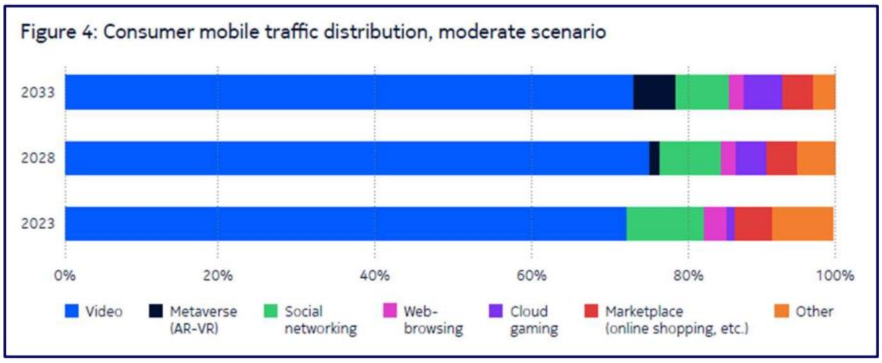

Figure 15 - Projections of internet traffic and usage to 2033. Source: (Nokia, 2024)

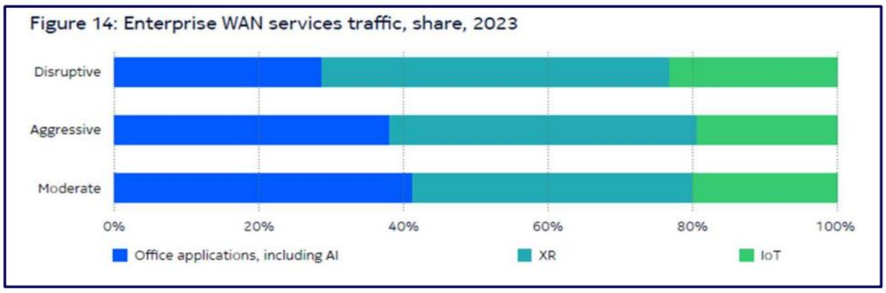

Figure 16 - Projections of internet traffic and usage to 2033. Source: (Nokia, 2024)

[34] T3 to T3

[35] In France too, the FFT predicts a growth in IP traffic by a factor of 6 from 88 Eo in 2020 to 526 Eo in 2030, driven by the increase in digital uses, the emergence of new technologies and the growth of user equipment (FFT, 2024).

To describe the place that AI would occupy in this traffic, these projections break it down into:

- Direct AI traffic: traffic with AI applications known as such or integrated into business productivity applications,
- Indirect AI traffic: traffic growth created by consumer engagement via recommendation algorithms and content personalization.

The approach is similar to other analyses (Ericsson, 2024), which identify the main driver of growth as the creation of hyper-personalized content at scale, which could drive growth in mobile traffic. The increased use of GenAI-based video assistants and immersive interactions could increase both upstream and downstream traffic (Ericsson, 2024).

Although the study (Ericsson, 2024) does not yet provide any quantified forecasts for additional traffic resulting from AI, the analysis of the trajectories produced in the prospective study (Nokia, 2024) shows that traffic (total, fixed and mobile) could be around 50% higher in 2033 than it would be in the absence of AI.

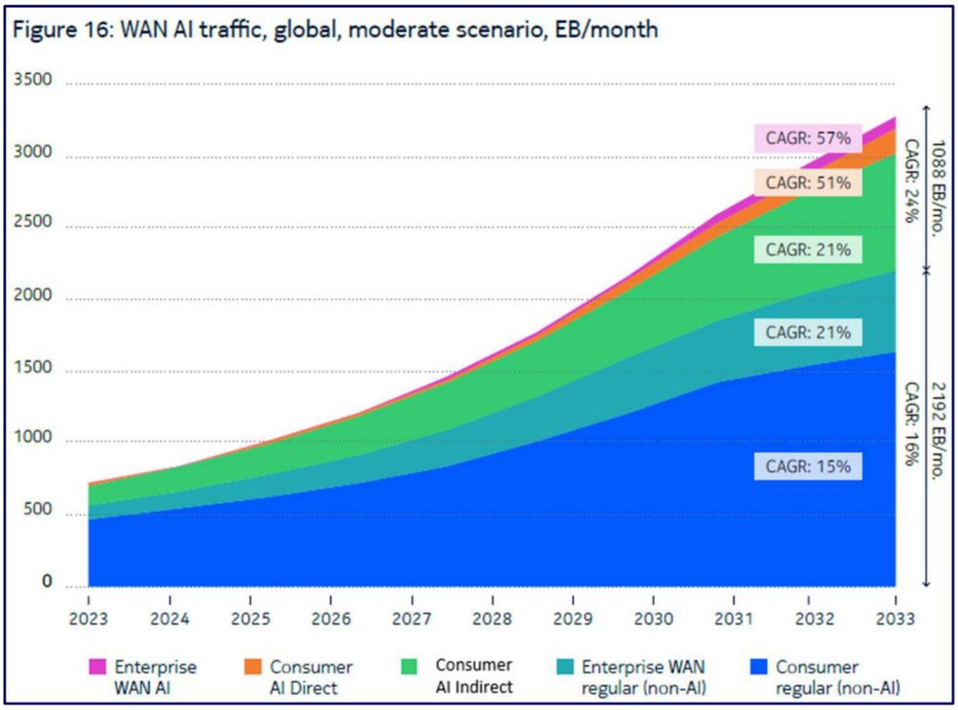

Figure 17 - Projected internet traffic to 2033, split between consumer and business, and AI-driven growth. Source: (Nokia, 2024)

These initial estimates must nevertheless be qualified:

- They are produced by organizations that are stakeholders in the value chain, for whom the anticipation of strong traffic growth is linked to commercial issues; It is also
- necessary to take into account possible network adaptations to respond to this traffic growth. This includes more efficient compression technologies, congestion management, and architectures dedicated to AI.

Beyond these considerations focused on growth in traffic volume, two aspects appear to have a potential impact:

- The multiplication of use cases with “real-time” type performance constraints would require reducing the effective latency of the technical chain used, possibly leading to increased densification of points of presence but also to a search for optimization within the cloud-network continuum, all of which is reflected in particular by the development of edge computing; • The ability given
to AI users to generate video or to interpret still or animated images would significantly increase upstream traffic while the current network architecture is designed to carry downstream traffic as efficiently as possible.

At this stage, we have not been able to quantify these consequences, which could however prove significant.

The analysis we have conducted to this stage leads us to identify the following questions for future work, following this interim report:

- Today, AI-related traffic seems minor and is not measured. How could this development be publicly observed? • Can artificial
intelligence multiply the creation of personalized content and be the cause of a possible increase in traffic?
- What are the indirect effects of recommendation algorithms (and therefore of AI) on networks?
- AI and digital technology in highly decentralized application cases (agricultural robotics, autonomous mobility) could (or could not) lead to an amplified deployment of networks (additional bandwidth, more efficient equipment to reduce latencies)?

All your comments, criticisms, suggestions on the data and directions explored at this stage, as well as any data research or interview avenues to be conducted, will therefore be a key ingredient for the continuation of this work!

Computing capacities in France and Europe: possible sizing, greenhouse gas emission trajectories, what governance to meet the challenges

While the previous chapter describes global dynamics and aims to shed light on their climate consequences, the driving force behind current global dynamics is not (largely) in our hands. This section aims to shed light on the issues these dynamics imply in France and Europe and the range of choices available to us, in terms of climate, electricity, and territorial implications.

In addition to the American energy wall (see previous section), the case of Ireland, with which we begin this section, will be unequivocal. Understanding the current situation in France will be a prerequisite: what are the energy needs of the digital sector, but also of other sectors?

The aim of this interim report will also be to discuss modelling needs at the French level.

All your comments, criticisms, suggestions on the data and directions explored at this stage, as well as any data research or interview avenues to be conducted, will therefore be a key ingredient for the continuation of this work!

I. The case of Ireland

Ireland is a country that has positioned itself as one of the European leaders in the digital sector with very proactive policies (particularly fiscal) to attract

investments. Major issues have emerged in recent years concerning the sizing of electrical infrastructure, usage conflicts between different sectors of activity, as well as shortages of renewable energy, which is nevertheless necessary to support the growth of data center deployment while remaining in control of the country's carbon trajectory.

Excluding data centers, electricity demand in Ireland has remained relatively stable in recent years. However, when data centers are included, demand increased by 24.7% between 2012 and 2022 (shown in red in the figure below) (Prof. Hannah Daly, University College Cork, 2024).

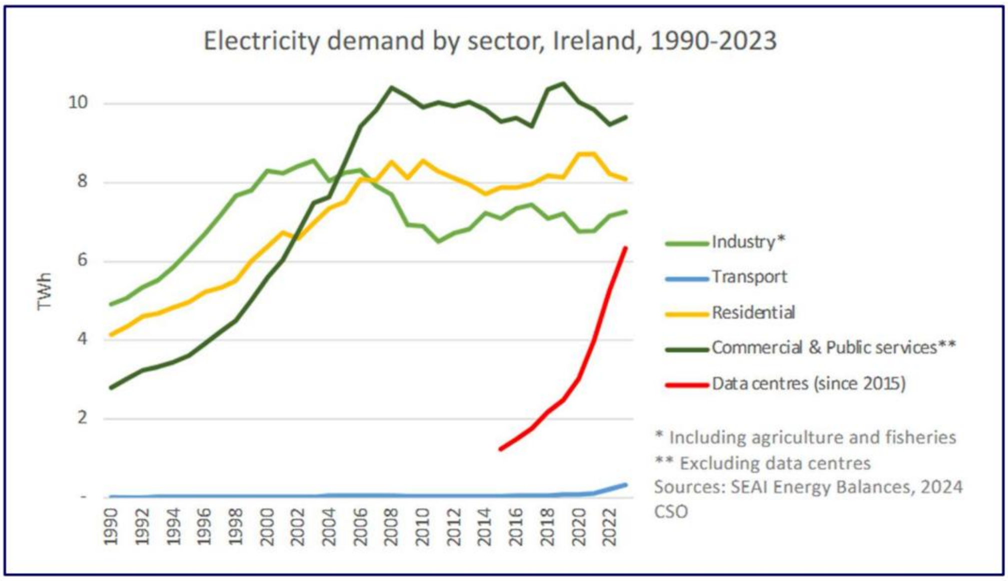

Figure 18 - Electricity demand by sector between 1990 and 2023 in Ireland. Source: (Prof. Hannah Daly, University College Cork, 2024)

According to official Irish statistics, data centers already consume more than 20% of available electricity, exceeding the electricity consumption of urban residential areas (Central Statistics Office (CSO), 2024; The Journal, 2024).

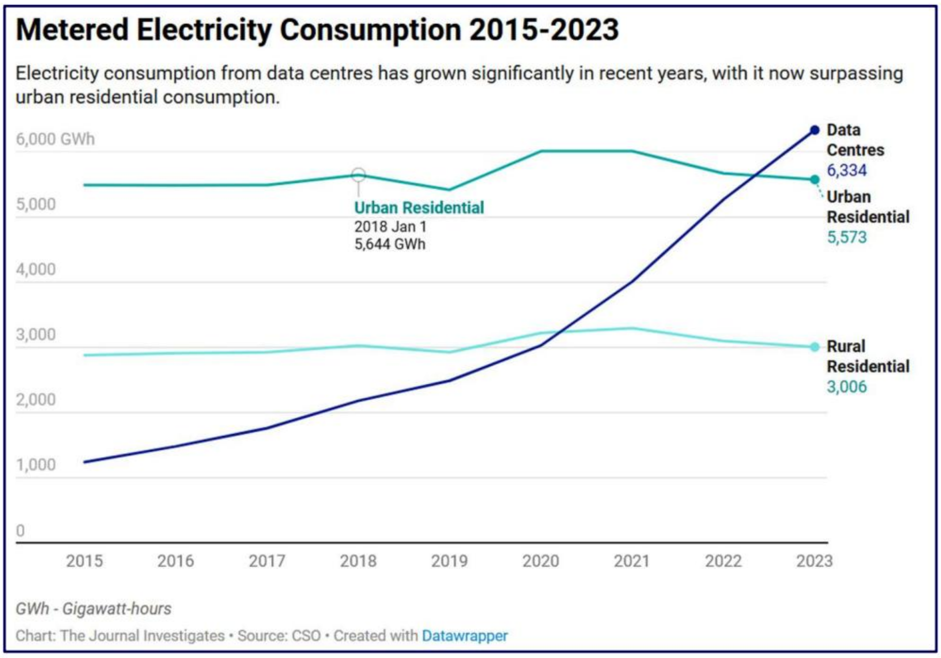

Figure 19 - Data center electricity consumption in Ireland, exceeding urban residential consumption. Source: (Central Statistics Office (CSO), 2024; The Journal, 2024)

Some projections predict that the sector will reach around 30% of the country's overall consumption by 2028, and the sector could even be, under certain scenarios, the largest consumer of electricity, overtaking the industrial and service sectors within a few years (IEA, 2024a; Prof. Hannah Daly, University College Cork, 2024).

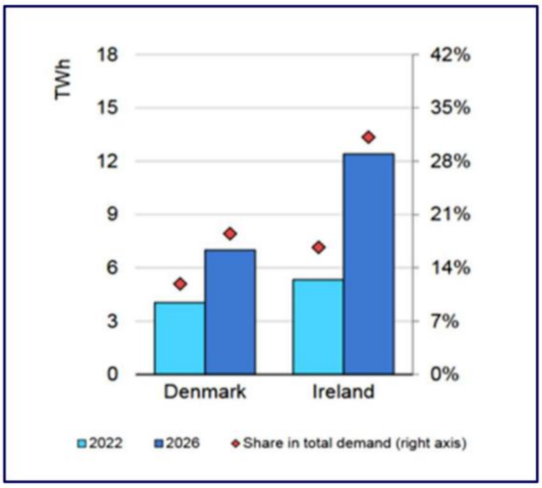

Figure 20 - Estimated data center electricity consumption and its share of total electricity demand in Ireland. Source: (IEA, 2024a)

The country's renewable energy sector, whose development was planned to ensure the migration of the overall energy mix in a context of moderate growth in demand, is now proving unable to meet new demands. To ensure their development, data centers are turning to natural gas power supplies in particular, and increasing the local use of backup and emergency generators powered by fossil fuels. In 2023, the Irish Environmental Protection Agency (EPA), responsible for issuing industrial license permits for installations with a capacity exceeding 50 MW, issued 13 licenses to data centers for the operation of

electric generators. This figure, which does not even take into account small installations that do not require an industrial license, raises serious concerns and indicates an increasing dependence on fossil fuels.

These energy access tensions are a bottleneck for the development of new projects and are prompting authorities to strengthen the criteria for granting permits for new data centers. In 2021, EirGrid, the national electricity network operator, imposed a moratorium on new site applications for the Dublin region, where the majority of data centers are concentrated, until 2028. In 2024, the South Dublin District Council highlighted "insufficient capacity of the electricity network and the absence of significant renewable energy on site to power the data centers," thus refusing a project in its territory by a major player in the field.

In addition to the American example detailed in the previous section, the case of Ireland illustrates that policies favoring the establishment of data centers at all costs can prove risky and counterproductive to the development of the sector, particularly in the absence of sufficient long-term strategies on energy systems, but also harmful when the use of fossil fuels is made. The business intelligence firm Gartner and the Epoch AI site even identify energy as a limiting factor for data centers, by 2027 for the former, with more than 40% of existing AI data centers by 2027 that could encounter operational constraints due to energy shortages, by 2030 for the latter (Epoch AI, nd-a; Gartner, 2024).

II. The state of affairs in France

A. Digital & climate

In France, the carbon footprint of digital technology for 2020 was estimated at 17 MtCO2e without including imported emissions from data centers (ADEME & Arcep, 2023). A double update published in January 2025 revised this assessment by covering the year 2022 and integrating imported emissions from data centers, thus bringing the carbon footprint of the digital sector to 29.5 MtCO2e (ADEME, 2025).

For 2022, the carbon footprint of the digital sector represents 4.4% of France's total carbon footprint, 46% of which is attributable to data centers, taking into account imported emissions (ADEME, 2025). However, as ADEME also indicates, this figure of 4.4% is probably underestimated, not taking into account the recent arrival of generative artificial intelligence or all the developments in the terminal fleet.

This update raises questions about how often energy and climate footprints should be measured to keep pace with the rapid pace of change in the digital sector.
This rapid pace of change also amplifies the importance of transparency in carbon data, as wasting months or years of research to reverse-engineer unsupplied data does not provide the right information in real time to make informed decisions.

B. Digital & electricity

In France, the electricity consumption of the digital sector is 51.5 TWh in 2022, or 11% of French electricity consumption (ADEME, 2025).

For data centers, for the past 5 years, projections have continued to increase for territorial electricity consumption:

- In 2022, RTE, in its study "Energy Futures 2050", declared 3 TWh of electricity consumption for 2019 and forecasts 5 TWh for 2030 in the "tertiary sector" category (RTE, 2022).

- In 2023, ADEME-Arcep, in its study "Evaluation of the environmental impact of digital technology in France and prospective analysis", models 11.6 TWh of electricity consumption for 2020 taking into account several types of data centers: colocation, HPC36, traditional for public actors and companies (ADEME & Arcep, 2023). Incidentally, in 2023 the Hubblo firm models 11.3 TWh for 2020 of cloud consumption abroad (Hubblo & Fourboul E., 2023).

- In March 2023, ADEME-Arcep projects 16 TWh for 2030 in the trend scenario and 39 TWh for 2050 (ADEME & Arcep, 2023).

- In December 2023, RTE, in its forecast balance sheet for 2035, forecasts between 23 and 28 TWh for 2035, still in the "tertiary sector" category (RTE, 2023) (chapter 2, p. 99, of which appendix 2A on assumptions is expected), and reassesses its vision for the start of the decade at 10 TWh.

- In 2024, RTE, in its network development plan, is studying 8 GW of demand for data centers37. These 8 GW translate into 25.3 TWh in Ile-de-France and 3.8 TWh in Marseille in 2040 (RTE, 2024) (document B). Assuming a utilization rate of 60%, this demand of 8 GW would correspond to 42 TWh.

- In 2025, RTE this time aggregates industry and data centers (no longer providing details for data centers, nor for industry for that matter) and projects 21 GW of signed connection contracts (RTE, 2025) (2025 Summary, awaiting sheet no. 5).

The uncertainty about the current state of data center energy consumption is already more than significant, by a factor of 1 to 4: between 3 TWh (RTE, 2022) and 12 TWh (ADEME & Arcep, 2023). Based on these same two studies, by 2030, the gap in 2030 is by a factor of 1 to 3: between 5 TWh (RTE, 2022) and 16 TWh (ADEME & Arcep, 2023). Part of this uncertainty about the state of play may lie in the scopes considered for these data38, which represents an area for improvement for future publications on this subject, conducive to better organization of the energy transition.

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[36] High-performance computing

[37] In September 2024, RTE said it had signed 4.5 GW of data center connection offers and "a equivalent volume" was under investigation (LeMagIT & Raoul G., 2025).
In February 2025, in its 140 projects signed for 21 GW, RTE lists 40 data center projects, for an average of 130 MW each, or 5.2 GW (LeMagIT & Raoul G., 2025).

[38] Tertiary sector on the RTE side, or power/voltage sufficiently high to be considered by RTE, or category of data centers.

It is imperative to make rapid progress on data sharing and quality, as well as on demand modelling: such high uncertainty regarding demand that is already significant and in any case growing strongly creates a definite risk for the 2033-2035 horizon.

All the more so since the installation of data centers on French territory is encouraged via:

- A significant reduction in taxes on electricity consumption (TICFE) for data center operators (Legifrance, 2022)39 ,
- An incentive policy with the simplification bill which aims to make data centers Projects of Major National Interest (PINM) which will speed up certain procedures (compatibility of urban planning documents, connection to the electricity network, recognition of imperative reasons of major public interest - RIIPM) (Public Life, 2024)40 ,
- A national strategic and commercial policy led by:
  - EDF offering 4 sites on its land for 2 GW and 2 new sites to come (DCMag, 2025b; Le Figaro, 2025),
  - The Elysée Palace was made visible during the Summit for Action on AI with the announcements of 3 1 GW sites (Le Monde, 2025a, 2025b; L'usine digitale, 2025),
  - The government announcing 35 ready-to-use sites for a total surface area of around 1,200 hectares (DCMag, 2025a; Le Monde, 2025a) (map at the administrative regional scale in Figure 21), with 15 of the 35 sites able to be connected to the high-voltage network and capable of reaching 750 megawatts of power (LeMagIT & Raoul G., 2025)41 .

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[39] Electricity is subject to a reduced excise duty rate for the fraction exceeding one gigawatt hour over a calendar year consumed for the needs of the real estate infrastructure which meets the following cumulative conditions: 1° It is dedicated to the physical storage, processing, transport and dissemination of digital data; 2° Its access is secure; 3° It includes specific and dedicated devices for controlling its thermal environment, its air quality, its energy supply and fire prevention; 4° It integrates an energy management system that complies with the criteria provided for in the second paragraph of Article L. 233-2 of the Energy Code; 5° The operator adheres to a program, recognized by a public, national or international authority, for the pooling of good practices in energy management of data centers including: a) Eco-design of data storage centers; b) Optimization of energy efficiency; c) Monitoring of energy consumption and the production of periodic reports relating thereto; d) The implementation of cooling technologies that meet performance criteria. 6° The fatal heat that it generates is used within a heating or cooling network or the installation complies with a quantified indicator over a multi-year horizon in terms of efficiency in the use of power, determined by decree; 7° The water used there for cooling purposes is limited according to a quantified indicator over a multi-year horizon, determined by decree;
8° The level of electro-intensity, assessed on the scale of this installation, is at least equal to 2.25%.

[40] For industrial-scale data centers, the bill plans to classify them as projects of major national interest (PINM), which will speed up certain procedures (compatibility of urban planning documents, connection to the electricity network, recognition of imperative reasons of major public interest - RIIPM).

[41] RTE lists around 50 source stations capable of accommodating 250 MW and around twenty capable of supporting 750 MW, not only dedicated to data centers (LeMagIT & Raoul G., 2025).

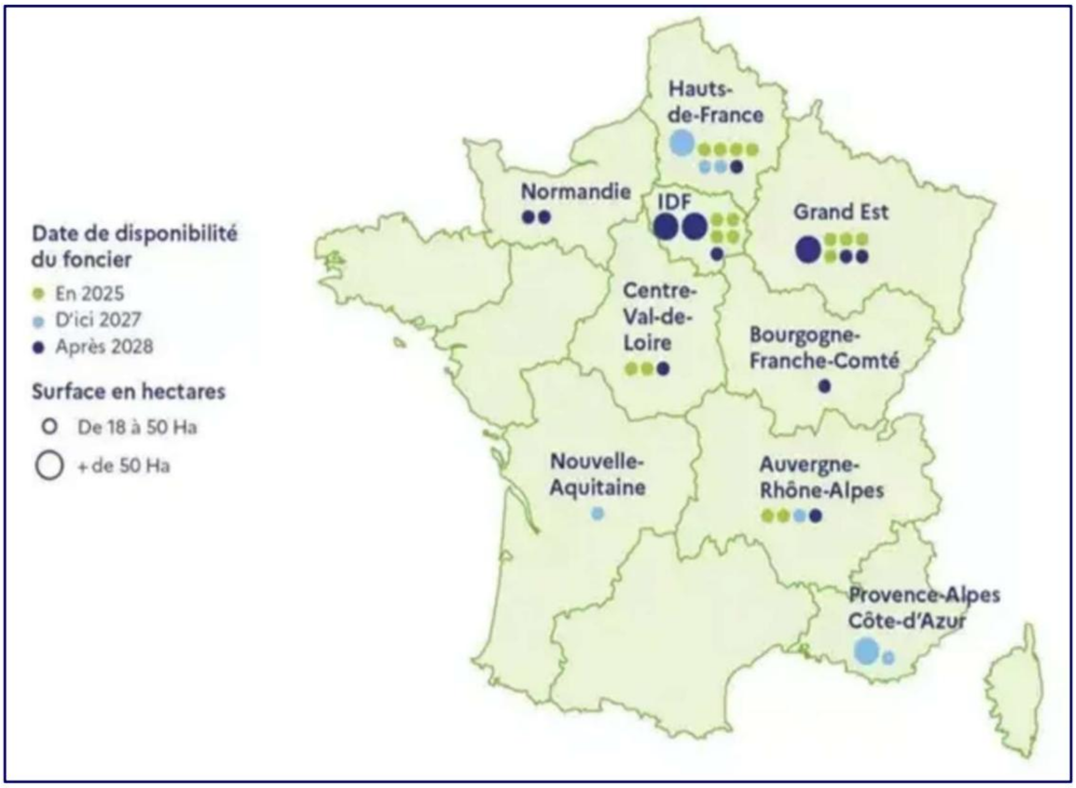

Figure 21 - The regional map of the 35 AI data center sites identified by the government.
Source: (DCMag, 2025a)

The electricity consumption of the digital sector has been a well-identified issue for at least 5 years (Sénat, 2020). However, there are still many (too many) questions regarding the knowledge and monitoring of the data center fleet. For example:

- What public inventories are available? For current and future projects? How often are they updated?
- What observatories exist? What are the anticipation needs?
- What are the channels of public debate?
- How is the evolution of more diffuse data centers monitored: enterprise data centers and small data centers?
- Some data centers concentrate high capacities on small surfaces: could this constitute a risk for the management of network balancing?

These questions seem essential in the face of this forecast of territorial integration of data centers, and in a context of energy and ecological transition, and all the more so since the projections are constantly revised upwards.

C. Digital & electrification of other sectors

1. The energy transition requires electrification of activities and control of demand

The energy transition envisaged by French prospective scenarios (RTE, ADEME in particular) is based on:

- Electrification of major economic sectors: all scenarios foresee significant electrification of equipment and processes, with varying intensity depending on the trajectories, particularly in buildings, mobility or industrial activities. Electricity becomes the majority source. Thus, the need for electricity production is increasing in almost all scenarios, but to varying degrees. For example, in the RTE reference scenario (RTE, 2022), total electricity consumption, at 454 TWh in 2020, is expected to reach 508 TWh in 2030, 567 TWh in 2040 and 645 TWh in 2050.

- Demand management: Reducing energy consumption is essential to achieving carbon neutrality, which cannot be achieved solely by decarbonizing energy production. This reduction is based on two pillars: sobriety and energy efficiency.

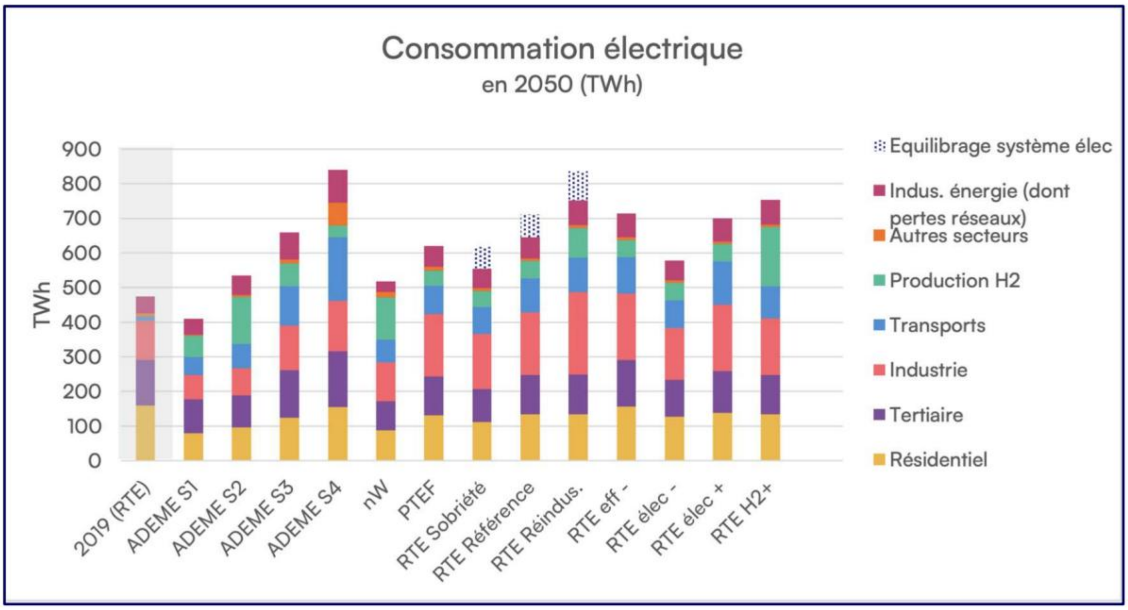

Figure 22 - Electricity consumption in 2050 according to the main French transition scenarios
Source: Site comprendre2050.fr, analysis “What will happen to electricity consumption for a low-carbon France?” (ADEME, négaWatt, The Shift Project, 2025)

2. Sectoral analysis of electricity needs by 2030-2035

At the sectoral level, the example of electricity needs by 2030 and 2050 in several sectors (transport, industry, residential, low-carbon hydrogen) will provide a representation of the transition as a whole, in order to illustrate the challenges of competition in the use of electricity between sectors, and to illustrate the anticipated efforts on demand; illustrations which can be put into perspective with the digital transition.

For the transport sector, electricity demand is growing in all scenarios, both to 2030 and 2050.

By 2030, transport electricity consumption is expected to increase significantly, from 12 TWh in 2020 to levels reaching up to 57 TWh in some scenarios.
For scenarios with intermediate assumptions (see Figure 24):

- **ADEME trend scenario (ADEME, 2021): 35 TWh in 2030 (+23 TWh, i.e. a multiplication by approximately 3).**
- **RTE reference scenario (RTE, 2022): 33 TWh in 2030 (+21 TWh, i.e. a multiplication by a little less than 3).**

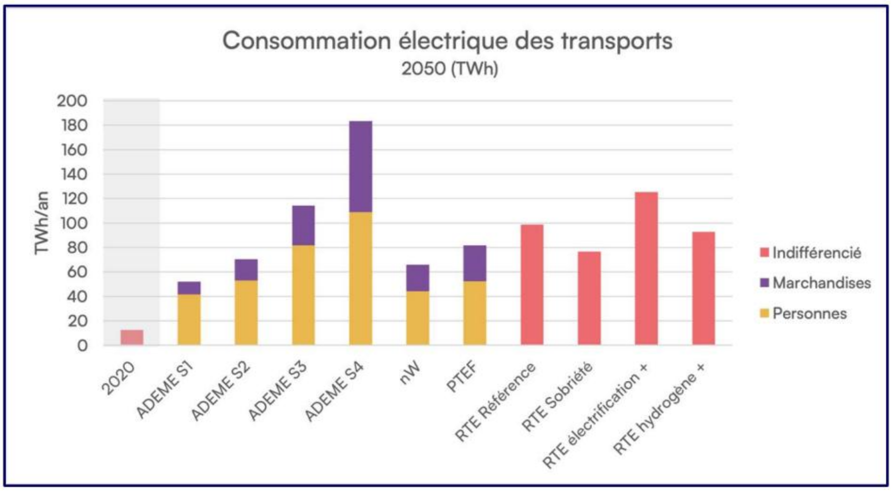

Figure 23 - Electricity consumption in the transport sector in 2050. Source: Website comprendre2050.fr, analysis "What electricity consumption in transport in the future?" (ADEME, négaWatt, The Shift Project, 2025)

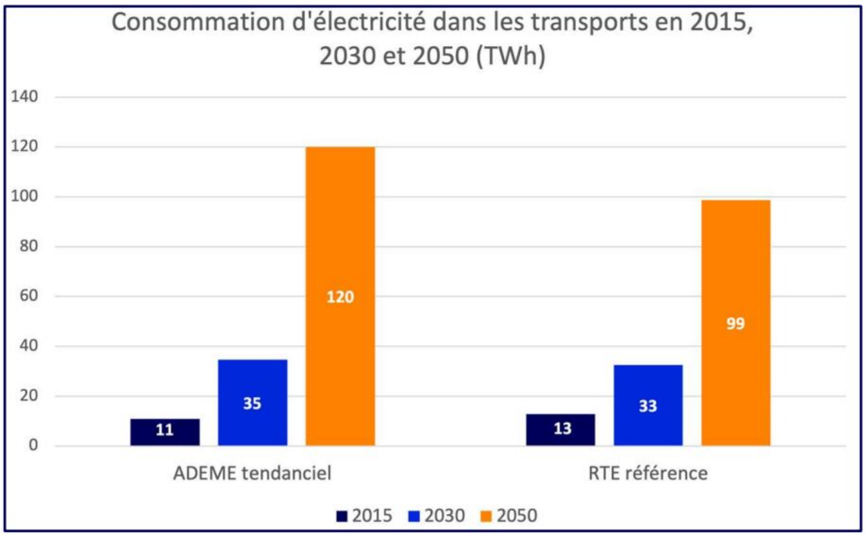

Figure 24 - Electricity consumption in the transport sector in 2015, 2030 and 2050. Source: (ADEME, 2021; RTE, 2022)

For the industrial sector, electricity demand is growing under most scenarios.

Industrial electricity consumption increases from 115 TWh in 2020 to levels as high as 123 TWh in some scenarios. For scenarios with intermediate assumptions (see Figure 26):

- **ADEME trend scenario (ADEME, 2021): 127 TWh in 2030 (+12 TWh).** • **RTE reference scenario (RTE, 2022): 113 TWh in 2030 (-2 TWh).**

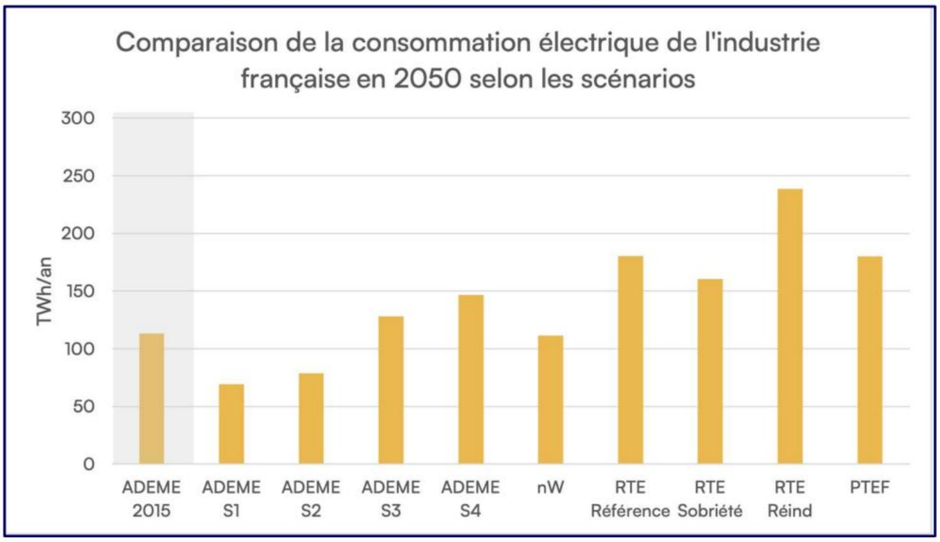

Figure 25 - Electricity consumption in the transport sector in 2050. Source: Website comprendre2050.fr, analysis "What will be the electricity consumption of industries in 2050?" (ADEME, négaWatt, The Shift Project, 2025)

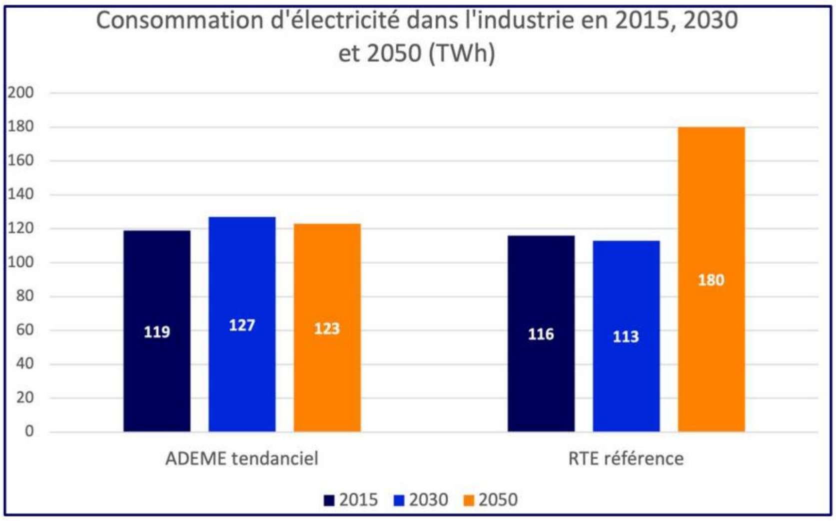

Figure 26 - Electricity consumption in the industrial sector in 2015, 2030 and 2050. Source: RTE Futurs énergies, ADEME Transition(s) 2050

For the residential sector, electricity consumption in the RTE reference trajectory is significantly oriented downwards under the significant effect of the improvement in energy efficiency:

- By 2030: from 159 TWh in 2020 to 151 TWh in 2030, i.e. –6 TWh compared to 2020
- By 2050: from 159 TWh in 2020 to 134.1 TWh in 2030, i.e. –25 TWh compared to 2020

Thus, the strong electrification of heating (70% of homes heated electrically in 2050 compared to around 40% today) must be more than offset by the downward effects of equipment performance, significant renovation of existing homes and new environmental regulations for new construction. Electricity consumption for heating would thus fall by 11.5 TWh or 25% in 2050 compared to 2019.

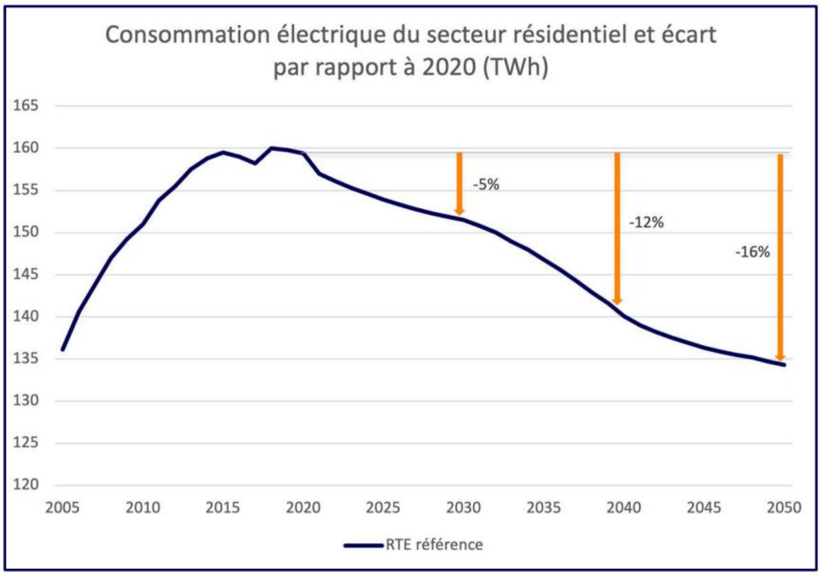

Figure 27 - Electricity consumption in the residential sector between 2005 and 2050 in the RTE reference scenario. Source: (RTE, 2022)

The development of low-carbon hydrogen is a major focus of France's energy strategy. By 2050, its use could increase by a factor of two to seven, depending on the scenario. Electrolysis using carbon-free electricity will become the central production method.

By 2030, electricity consumption in this sector increases from 0 TWh in 2020 to levels reaching up to 86 TWh in certain scenarios. For scenarios with intermediate assumptions:

• ADEME trend scenario (ADEME, 2021): 22.3 TWh in 2030. • RTE reference scenario (RTE, 2022): 25.1 TWh in 2030.

Today, RTE ensures transparent and non-discriminatory access to network users. It is not up to the government to decide how different sectors use electricity: national planning through the French energy transition roadmap, the SNBC, is therefore essential. This planning requires taking into account the needs and characteristics of each sector in terms of electrification:

- In terms of electricity consumption (TWh), capacity required (GW),
- But also in time scales: for example, the creation of a low-carbon hydrogen sector targeted by public policies is on a horizon of 10-15 years,
- And considering the challenges of achieving the transformations: deployment of capacities technological, necessary financial means etc.

3. The place of data centers and the digital sector in the energy transition is all the more uncertain

Estimates of current consumption in the sector are uncertain (see paragraph "Digital & electricity"), which necessarily makes the outlook for 2030 and 2050 all the more delicate.

In 2022, RTE assumed an increase in electricity demand from data centers, but based on a low volume. Thus, in the reference trajectory (in dark blue on the Error! Source of the reference not found.), RTE anticipates a tripling of data center consumption, going from 3 TWh in 2019 to 5 TWh in 2030 and 9.5 TWh in 2050 (in ultramarine blue on the Error! Source of the reference not found.).

In 2023, the ADEME-Arcep study proposes a trend scenario for the annual electricity consumption of data centers: for 2030 and 2050, they are respectively 16.4 TWh and 39.0 TWh (in orange on the Error! Source of the reference not found.). In orange are indicated other projections of the consumption of data centers. And finally, projections of another competitive sector are also indicated: mobility (in yellow on the Error! Source of the referral not found.).

These values are based on trend scenarios: they are therefore not the maximum possible values.

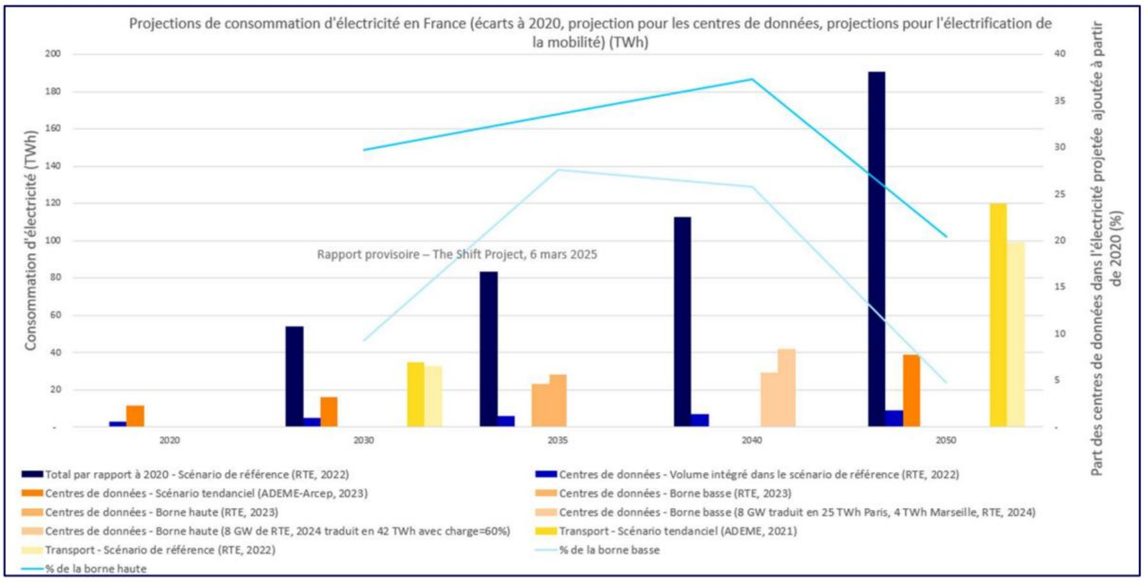

Figure 28 - Electricity consumption projections in France (deviations from 2020, projections for data centers and for the electrification of mobility). Sources: (ADEME & Arcep, 2023; RTE, 2022, 2023, 2024)42

In turquoise blue (reading on the right axis), the shares of data center consumption in the projections of electricity addition from 2020 (reference to 454 TWh) to 2030 (508 TWh, i.e. + 54 TWh compared to 2020) and 2050 (645 TWh, i.e. + 191 TWh compared to 2020) are represented.

- The addition of 11 TWh (16 TWh - 5 TWh, taken into account) between 2020 and 2030 according to ADEME-Arcep would represent 30% of the electricity addition of the RTE reference scenario between these same dates.

- The addition of 20 TWh between 2020 and 2035 according to RTE's forecast balance sheet would represent 31% of the electricity addition in RTE's reference scenario between these same dates.

- The addition of 30 TWh between 2020 and 2050 according to ADEME-Arcep would represent 20% of the electricity addition in RTE's reference scenario between these same dates.

The current dynamics of the deployment of data centers therefore raise questions about the distribution of electricity added to the network which would be consumed in France43 according to the scenarios and therefore, in practice, about the quantity of electricity available (production + imports).

Beyond the significant uncertainties surrounding digital technology, one question has not yet been asked and must be asked quickly: what share will energy sobriety and efficiency occupy in this sector? While scenarios are sometimes already very optimistic regarding energy sobriety and efficiency efforts, can we bet on this in a sector with such current momentum as digital technology? In which sectors is sobriety preferable: mobility, industry, or digital technology?

[42] For 2040, the Ten-Year Network Development Plan (SDDR) published by RTE in 2024 announces up to +8 GW in capacity for data centers in 2040. Assuming a utilization rate of 60%, this would represent a consumption of 42 TWh in 2040.

[43] As well as the balancing role of neighboring networks (in the United Kingdom and Germany) during the winter in particular.

4. Data centers can also be electricity producers although they are net consumers of electricity.

One of the key elements in the transformation of electricity systems towards decarbonization is the deployment of variable renewable energy sources, such as solar and wind power, whose production depends on weather conditions and is therefore not guaranteed at all times. This raises issues of instantaneous supply-demand balance for the electricity grid. In different energy scenarios, the higher the level of integration of intermittent renewable energies, the more crucial the challenge of deploying flexible capacities (for example, in the French case: (RTE, 2022)). The flexibility of a means of electricity production, consumption or storage is its ability to modify the time of electricity supply or consumption from the grid.

This characteristic is often mentioned in relation to data centers. In order to ensure the business continuity required for the most critical services, data centers must be equipped with power generation systems disconnected from the grid that will take over in the event of an incident on the latter. To do this, data centers are traditionally equipped with generators. However, the climate and renewable energy integration objectives of the players, combined with the improvement in the performance of electric batteries, are leading some of them to equip themselves with battery energy storage systems (BESS in English44) instead of these generators45 .

In addition to intermittency management, the very rapid mobilization of stored energy via BESS can also allow data center operators to sell, in addition to IT services, load shedding46 or electricity grid balancing services by using the power and energy available within their battery systems. This position allows data centers to doubly justify their status as a strategic and priority industry: both as a leading player in the digitalization of the economy, but also as a potential stakeholder in the decarbonization of the economy47. This position can and must question:

- By positioning data centers as suppliers of energy or services to electricity network managers, the electricity system could become partly dependent on the digital sector, at least locally.

- Since deployable battery capacities are limited (constraints on physical resources, structuring and mobilization of value chains, etc.), the question of competition for access to and use of electric batteries arises, in a context of intense electrification needs throughout the economy for its decarbonization (mobility, industry, direct use by electrical infrastructures for their balancing, etc.).

- The intense development of data centers posing crucial challenges in terms of energy availability and the conditions of compatibility of these dynamics with the decarbonization of digital technology and the economy as a whole, the possibility of a role

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44 Battery Energy Storage
System 45 See https://blog.se.com/datacenter/2024/05/01/the-rise-of-bess-powering-the-future-of-data-centers/ 46 A method of managing electricity consumption, whereby an industrial company voluntarily reduces its consumption (for a fee), at the request of the network manager. Load shedding can relieve the network when consumption demand is too high compared to production.
47 See in this regard the comments on the draft decree and order relating to emergency measures defined in application of Articles L. 321-17-1 and L. 321-17-2 of the Energy Code establishing the list of categories of consumption sites exempt from the obligation to provide emergency generators (https://www.consultations-publiques.developpement-durable.gouv.fr/projets-de-decret-et-d-arrete-relatifs-aux-mesures-a2754.html)

The structuring and essential role of data centers for the decarbonization of the economy via this positioning remains to be demonstrated, particularly in light of the phenomena documented in this report.

III. A first reflection on possible models and their objectives

In this section of the interim report, we propose to explore a number of questions related to data center impact modeling and associated climate and energy objectives. We would welcome your feedback on this chapter as a whole.

What are the benefits of modeling the various possible developments for data centers: evaluating the electricity consumption and greenhouse gas emissions of new data centers to describe their effects on energy and ecological transitions?
What models exist? Do they already inform public decisions?

What are the different types of data centers? Are the questions general or do they depend on the different types of data centers? What are the relevant geographic scopes and granularities? What are the different types of offers, uses, and needs? Are there different data storage and computing needs? What are the mitigation and climate change trajectories to consider? What scenarios would be relevant to describe?

What information is needed to model energy consumption and predict the climate impacts of data centers? What data should now be collected to implement appropriate data center policies? What sources or benchmarks exist?

A. Energy and climate lighting objectives

Predicting the various options for data centers, and more broadly for the energy transition that the digital sector is nibbling away at, seems to be becoming essential. The importance of these forecasts seems all the more important given that the trade and tax policies driving the massive deployment of data centers do not seem to be aligned with sustainable and resilient energy and territorial policies. Behind investments in data centers and AI lie many structural decisions that can easily weaken the electricity transition, especially if it is disorderly.

From a climate perspective, the digital sector's share of the carbon footprint is increasing, with other sectors not planning to reduce their emissions to offset the additional digital emissions. This disruption must be controlled and rectified quickly, or it could jeopardize our climate goals. What are the greenhouse gas emissions of new data centers?

B. Criteria, constraints, scope, division

- What are the criteria to consider and the questions to ask to identify them?

- Electricity consumption, territorial greenhouse gas emissions, French carbon footprint?
- How to highlight possible impact transfers between energy and carbon (renewal for more efficient equipment for example)?
  What global optimum should we seek?
- How can we model the effects of other impact criteria such as water consumption, waste generated, soil artificialization or even pressures on mineral resources, in addition to the classic approach (energy, carbon) of the Shift Project?

- What constraints must be taken into account?
  - Given the warming trajectories we are on, do the characteristics of the locations where data centers are located define new constraints: areas that are prohibited because they do not have the volume of water required for data centers in periods of drought and high heat? areas that are prohibited because they are likely to create heat islands in cities?
  - Given the mitigation trajectories we are committed to, how can we model the impact of land artificialization linked to the establishment of new data centers, particularly in natural areas (meadows, forests, urban wastelands)?
  - Are there energy, climatic, material and financial limits to model as constraints?
- What geographical area should be considered?
  - France initially.
  - What would be the benefits of modeling data centers in Europe?
  - A scope allowing us to describe the “imported” part of our digital consumption, and the resulting dependencies?
- What geographical division should be chosen for this model?
  - By region to be able to take into account local constraints: whether for land, for RTE stations, for latency issues (proximity to interconnections (IXP), proximity to users or data)?
  - By country to be able to take into account different electricity emission factors (if the geographical area considered is European)?
- The word “data center” is today a portmanteau word that covers sizes (in m2 or IT GW), business models (on-prem, service providers, colocation infrastructure providers), uses (versatile, specialized in cloud, compute, storage, training, inference, etc.) and very different technical characteristics. What typology of data centers should be defined since:
  - Hardware (server types, renewal frequencies) differs depending on the type of data center.
  - Cooling and energy installations vary depending on the types of data centers.
  - What features will be available in the EED statement?

• The typology we propose is available in Appendix 1: edge, enterprise, telecommunications service providers, colocation or co-hosting, hyperscaler.

• Is there any point in separating data centers by type of electricity supply (Enedis, RTE)? Or even in modeling privatized electricity networks?

C. Modeling

From an energy/climate perspective, one way to start this work is to ask three successive questions:

• What usage trajectories?

• What efficiency trajectories?

• What energy trajectories?

This amounts to starting from a model close to the Kaya equation (as in the publication (Ni W. et al., 2024)):

$$\boxed{C = D \times \frac{E_{data}}{D} \times \frac{E}{E_{data}} \times \frac{C}{E} = D \times e \times PUE \times f}$$

Or :

• These are the total greenhouse gas emissions (in MtCO2e),

• D represents the measure of the computing demand of the data centers considered (in EFLOPs, floating point operations per second)48 ,

• Edata represents IT energy consumption in data centers (in kWh),49

• E represents the total energy consumption of the data centers measured (in kWh),

• e = Edata / D represents the energy consumption per computing unit, or energy intensity of data centers (in kWh/EFLOPs),

• PUE = E/Edata represents the commonly used metric to measure the energy efficiency of data centers,50

• f = C/E represents the overall intensity of data center emissions (representative of the electricity emission factor, but also of the on-board footprint of the equipment, dividing by the duration of use in the case of a “stock” model).

[48] This demand for calculation can be expressed in relation to the capacity available via the load.
[49] Idle power consumption must be carefully considered in Edata or E.
[50] Please note that different types of PUE coexist: PUE 1 = everything that comes out of the inverters; PUE 2 = everything that enters the power strip supplying a rack; PUE 3 = everything that comes out of the power strip supplying a rack.

From this base, and by summation games, it is possible to specify this model with for example:

- Different formulations of supply and demand (of operations but also traffic For example),
- Different regions (in France, or in Europe),
- Different types of data centers, which have different efficiencies and PUEs.

Still from this basis, it might be wise to add:

- A variable representing the duration of installation of a data center, which could aggregate durations such as those for compatibility of local urban planning plans, approval, environmental authorization, building permits, land acquisition, electrical connection, digital connection and connection to renewable energy production (see graph p22 (L'institut Paris Région, 2023)),
- A data center fill profile, and the identification of variables that are dependent on fill (e.g. PUE), possibly taking into account the hardware availability of the servers,
- A PUE profile, depending on the geographical areas (temperature and depending on the cooling technologies) possibly,
- A load rate profile, possibly modeling different policies energetic,
- Variation in consumption over the course of days or years in order to model consumption peaks, or not. This would allow us to consider possible oversizing, current allocation or even hyper-allocation strategies of digital players (in response to material profitability or even commercial strategies for services sold during "digital off-peak hours"), the systems used today in the event of breakdowns ("buffer" batteries and flywheels before the ignition of diesel gas emergency generators) and requests for possible flexibility.
- Taking into account hardware depreciation periods: what are the lifespans of servers and what happens to the elements once replaced? And how can we take into account differentiated obsolescence of types of IT equipment in servers since the impacts on manufacturing and consumption are also different: what are the respective lifespans for CPUs, GPUs, RAM, power supplies, cards, disks? and what are the differentiated technological developments?
- Generally speaking, consider the evolution of these variables according to different phases of the data center: ramp-up (~3 years?), nominal use (~15 years?), end of life.

If we focus on supply and demand modeling:

- The modeling of a number of racks and a kW/rack power would be a variable representative of the installed offer (this is for example the case in the study (Schneider Electric, 2023)).

- Modeling the surface area used and a profile of the evolution of the power density (kW/ m^2) per surface area would be a similar variable (this is for example the case in (ADEME & Arcep, 2023)).

- More macroscopically, the distribution of data centers with their power (GW) would be an interesting variable as it would allow us to rely on the common rating system for data centers at the European Union level to come (Official Journal of the European Union, 2023). But how to model possible developments: from a list of projects in progress and the probabilities of completion?

- It would also be possible to separate computing capabilities into "data" (data storage) and "compute" (data processing), a way of taking into account developments towards more computing activities as well as modeling developments by type of hardware, the associated trends, in order to identify optimization levers on the different types of hardware (storage, traditional computing, AI, etc.).

    - In the "Methodological framework for environmental assessment of IT hosting services in data centers and cloud services" (ADEME, 2023), there are two distinct functional units for: "making available a physical server hosted in data centers with a given computing capacity" or "given storage".

    - For specialized AI data centers, demand could potentially be modeled as a "token".

- It might be interesting to separate by types of uses: cloud, storage, AI, generative AI, training, inference, in order for example to model various rates of evolution for each of these uses.

- It might be interesting to separate by user types: companies, individuals and same "robot"[51] .

- Supply/demand modeling must be taken into account in a differentiated way according to the types of data centers to invite in particular reflection on the evolution of computing capacities in companies, at the edge, as well as on specific AI or even specific training data centers (on this subject see the study by De Vries on the bottom-up starting from the number of GPUs sold or planned (de Vries A., 2023).

D. Screenwriting

Different scenarios can be considered:

- The reference scenario could be a "Trend + Sustainable AI" scenario, a way of reflecting the position of the Summit for Action on AI (Elysée, 2025), namely a trend scenario on demand, including eco-design levers. Which levers with what magnitudes would be representative of this "Sustainable AI"?

- A "Trend" only scenario;

[51] In the sense that bots are increasingly numerous and generate uses "alone" or rather in an "automated" way (Thales Group, 2024).

- Two inflationary scenarios, with or without exceeding low-carbon electricity production capacities;
- An "Ecodesign and sobriety" scenario;
- Scenarios affecting material, land, energy or climatic limits.

IV. Territorial and regional integration of data centers: initial questions for a resilient strategy?

In this section of the interim report, we propose to list certain effects and to explore the questions that this should raise, without, however, claiming to exhaust the subject.

Your feedback, criticisms or suggestions on the questions asked and the directions explored at this stage will be key elements in the next stages of this work!

In order to enable sustainable development, both for regions, territories and economic sectors, the regions and territories hosting and integrating data centers will now have to integrate several essential elements into their strategies, including:

- The warming trajectories we are on, which may define new constraints (e.g.: prohibited areas because they do not have the volume of water required for data centers in periods of drought and high heat, prohibited areas because they are likely to create heat islands in cities, etc.),
- The mitigation trajectories on which we are committed, which can also define new constraints (e.g.: Zero Net Artificialization objectives, preservation of natural areas (meadows, forests, urban wastelands, etc.)),
- The change in scale of data centers, which for some may now be at the same level of concentration as certain large-scale industries[52] enacting a change of scale from tertiary to industrial (Carnino, Marquet, 2022).

In light of these three major trajectories, while the positive and negative externalities of data centers (employment, attractiveness, air pollution, limited water resources, land, energy, climate, environment, etc.) remain relatively stable in nature, their quantitative impacts can vary and even cross critical thresholds. Thus, an externality deemed minor yesterday could become significant tomorrow.

[52] As the IEA illustrates, in the United States, data centers are more spatially concentrated than factories. steel, coal and ore mines, power stations and warehouses (IEA, 2024b) (fig 4.12).

V. The state of play in Europe

The European scale is interesting for observing what is happening in other countries, particularly the adequacy between different energy policies (fiscal, industrial, digital, climate, energy, etc.), but also for controlling energy consumption and greenhouse gas emissions at its scale.

The Borderstep Institute has developed a model for data centers at the European level, feeding into a scenario proposed in 2020 as part of the European Commission's work on cloud and data centers (Figure 29) (European Commission, 2020).

In 2024, the European Commission conducted a study on the energy consumption of data centers in Europe (EU27) (Figure 30) (European Commission, Kamiya G., Bertoldi P., 2024).

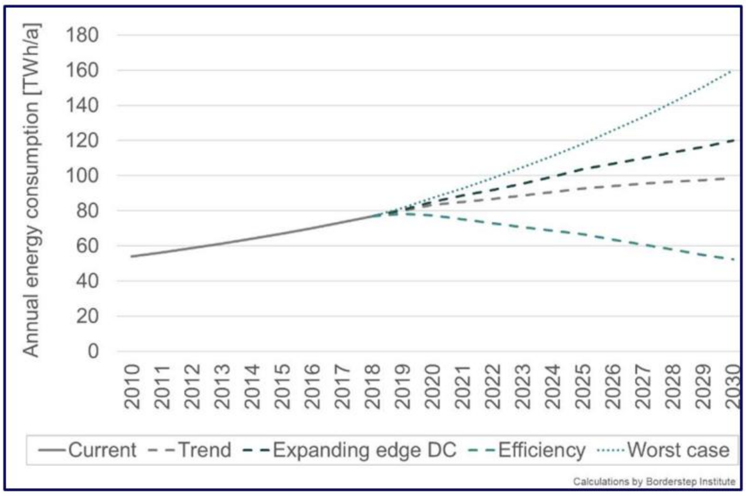

Figure 29 - Possible scenarios for the evolution of data centre energy demand in the EU28 until 2030. Source: (European Commission, 2020).

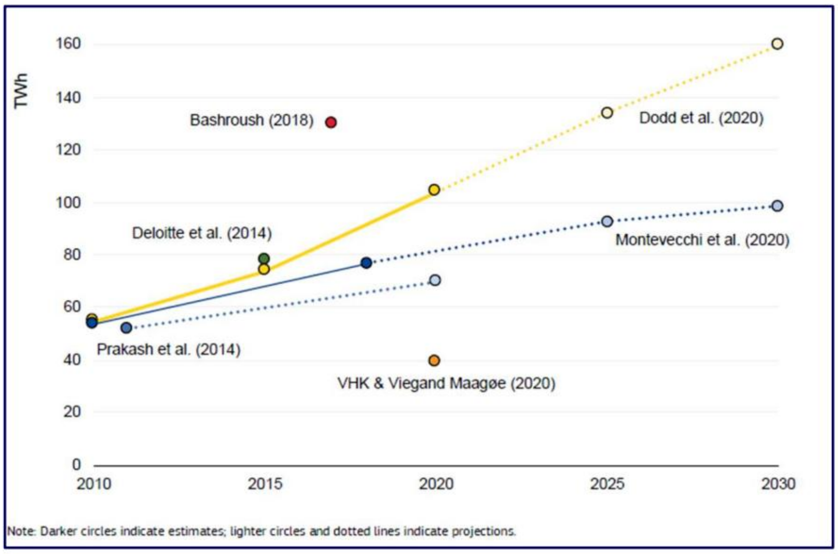

Figure 30 - Estimates for the energy consumption of European data centers. Source: (European Commission, Kamiya G., Bertoldi P., 2024)

In 2018, EU (EU28) data centers consumed 77 TWh of energy.

According to the European Commission (European Commission, 2024), this consumption would increase significantly by 2030: in 2018, a 28% increase was already predicted, but now, with – generative – AI, a two- to three-fold increase is anticipated for some countries. Within the Union, data centers represented 2.7% of electricity demand in 2018 and could reach at least 3.2% by 2030 if development continues on the current trajectory (European Commission, 2024).

According to a report by the European Commission (European Commission, Kamiya G., Bertoldi P., 2024), data centers in the EU27 will consume between 45 and 65 TWh of electricity in 2022, or between 1.8 and 2.6% of total electricity consumption. This estimate is slightly lower than that of (Montevecchi, F. et al., 2020) who estimate that data centers accounted for 2.7% of total electricity consumption in the EU28 in 2018.

In 2024, the International Energy Agency estimated an electricity consumption of 100 TWh for Europe[53] in 2022, with a projection of 150 TWh for 2026 (IEA, 2024a).

For its part, the strategy consulting firm McKinsey proposes a reference scenario targeting 150 TWh in 2030 for Europe (EU27 + United Kingdom), an increase of 85 TWh between 2023 and 2030. This would bring the share of data centers in European electricity demand to 4.5%. This growth is notably attributed to hyperscalers (70% of the expected demand by 2028) and colocation data centers. According to McKinsey, 25 GW of IT capacity could be installed by 2030, which would represent 15 to 25% of all net new European demand until 2030 (McKinsey & Company, 2024).

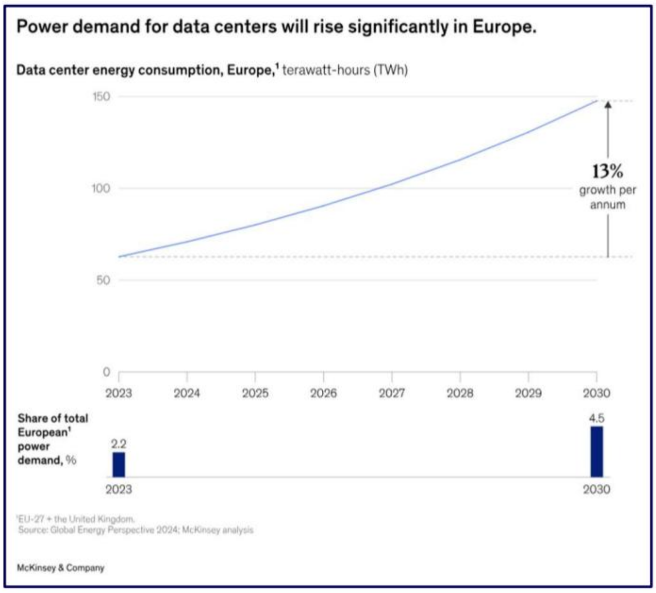

Figure 31 - Projected energy consumption of data centers in Europe in TWh. Source: (McKinsey & Company, 2024)

[53] Geographical perimeter to be clearly identified according to the studies.

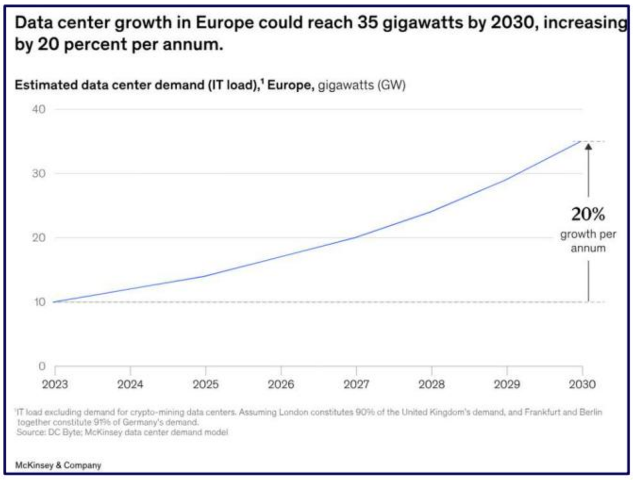

Figure 32 - Projected demand for IT capacity installation in Europe GW. Source: (McKinsey & Company, 2024)

In this context, it is crucial to note that these dynamics are very concentrated (Figure 33) in a few areas, with:

- Two-thirds of data center energy consumption for four countries: Germany, France, the Netherlands and Ireland, although they only represent 40% of the European population,
- The share of national electricity consumption being very heterogeneous, reaching 18% in Ireland, 5.6% in the Netherlands or 4.9% in Luxembourg and 4.6% in Denmark, •
The twelve main markets, which this study estimated on the basis of national data, represent approximately 95% of the energy consumption of data centers in the region (European Commission, Kamiya G., Bertoldi P., 2024).

The European ecosystem is therefore characterized by significant regional disparities in data center implementation dynamics. In this context, the European Commission and each country must be able to guarantee the controlled development of data center projects, while respecting regional constraints, national electricity capacity development roadmaps, and carbon footprint reduction commitments.

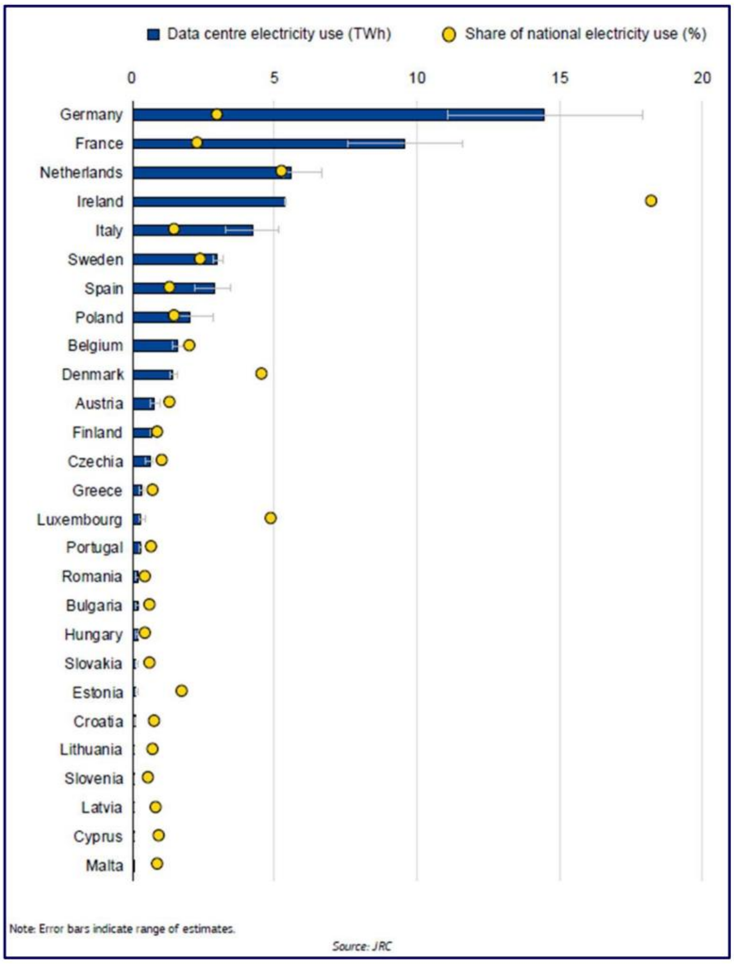

Figure 33 - Estimated energy consumption of data centers by country in EU27 in 2022 in TWh , Source: (European Commission, Kamiya G., Bertoldi P., 2024).

According to the European Commission, large data centers (including colocation data centers and hyperscalers) represent around 65% of the total, compared to 35% for enterprise data centers54 (European Commission, 2024).

It seems important to us, in the further work following this interim report, to compare these upward projections for data centers with European energy capacities.

At the European level, the Energy Efficiency Directive, which structures the European Union's regulations for promoting energy efficiency and reducing energy consumption, has been revised and now requires data center operators to report their key performance indicators such as power consumption, computing performance or network bandwidth requirements (Official Journal of the European Union, 2024).

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[54] The report compares this distribution to the estimates of (Dodd N. et al., 2020) which estimated a 56/44 distribution in 2020 and predicted a 66/34 split in 2025.

This update of the directive aims to increase transparency in the field, by establishing a European database of relevant data for the energy performance (and water footprint) of data centers and also to promote new designs and developments in efficiency.

With the delegated regulation on the data center rating system, the European Union will be able to collect information on data centers and assign sustainability indicators, which is a first step but probably not enough to change the curves of energy consumption and greenhouse gas emissions.

Many questions can be asked at the European level:

- **What will be the future of carbon emissions from data centers in Europe? Can emissions be included in the EU-ETS emissions trading system?**
- **Will the twin transition vision (combining the ecological and digital transitions) incorporate considerations on the climate sustainability of digital infrastructure?**
- **What will be the role of European policies in addition to national and local policies on the climate objective of the digital sector?**

AI serving the general interest must meet the challenges of climate change and energy transition

I. Use case approach: what services and technological promises for AI?

Uses and infrastructure are two sides of the same coin: the scale we assign to AI services and applications is directly linked to the physical computing, processing, storage, and data transmission media we deploy to make them possible. The dynamics described in the previous section allow us to understand the macroscopic physical trajectories within which our uses may be embedded.
However, there are many possibilities regarding the mix of services and applications that will actually develop on these bases.

A. AI and generative AI: a technological breakthrough?

The definition of "artificial intelligence" is less prescriptive than dynamic: the technological horizon is shifting. Simplifying, we could say that AI refers to the most advanced automation applications, at a given time, in terms of information processing, task complexity, precision, and reliability.

The principle of digital technology is to produce output data in response to input information to which it applies specific rules. The technological paradigms of our information processing machines have, however, diversified, particularly with the development of machine learning. The latter automates, at least in part, the construction of the rules to be applied: rather than relying exclusively on humans, the digital system is first responsible for developing its own rules. It generates them on the basis

of a statistical analysis of the links existing between input data and expected outputs[55] ,
before applying them in turn.

The work presented in this report is in line with the conclusions of the report of the Commission on Artificial Intelligence (Commission on Artificial Intelligence & French Government, 2024) regarding the definition to be given to our object of study: the new application dynamics of AI arise from an increased availability of data stored and exploitable by computing infrastructures of increasing size and complexity.

Generative artificial intelligence is one of the most visible advances. The specificity of this new family of algorithms is its ability to generate information, based on four characteristics generally found in the services that comprise it (Artificial Intelligence Commission & French Government, 2024):

- The information produced is often perceived as realistic, that is to say that it is difficult to identify that it is content produced by an algorithm (coherent texts, realistic images, vocal content with convincing intonations, etc.);
- Information is produced quickly: interactions with these tools are fluid and allow for a rapid response on a human scale, in the order of a few seconds;
- Versatility: the information produced can be of very different natures, and sometimes complex, while maintaining a high degree of reliability, that is to say that the information remains realistic even for tasks with multiple and precise instructions;
- The human-machine interaction required to produce information is simple (chatbot, voice interactions, etc.), meaning that the interaction feels natural to a human being.

These four characteristics, pillars of the originality and rapid penetration rate of services based on generative AI, are made possible by the large quantities of data and computing capacities available for training models. It is the implementation of an intense training phase upstream of the inference phase (use phase) that makes it possible to produce a system that can be particularly responsive and adaptable while remaining sufficiently reliable. Large Language Models (LLM) are a central building block of these new systems.

While the supply of promises and projections of services currently classified in the "artificial intelligence" category is boosted by the broad deployment of generative applications, there is actually a multitude of possible functionalities hidden, based on generative technology or not. Since algorithmic and data acquisition/processing technological building blocks are an integral part of many applications already deployed, generative AI should be considered as an additional technological building block that can be mobilized to provide a given service. Given its particularly significant infrastructure intensity compared to other types of technological solutions, asking the question of its necessity to provide the desired service will be inevitable in the context of designing digital goods and services compatible with the double carbon constraint.

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[55] For example, by asking him to calculate the "probability" of occurrence of a word following the words which precede it, based on a corpus of texts.

While the previous axis of the report allows us to draw up a macroscopic picture of the carbon-energy challenges of data and computing infrastructures, the aim here is to provide a reading grid based on the desired services. The work presented in the following pages aims to provide benchmarks for stakeholders to shape and guide the design and deployment of applications labeled "AI" in such a way as to make them compatible with dynamics fueling sustainable digital trajectories, rather than making them deleterious. The method proposes to identify and characterize:

- The technological building blocks underlying a service proposal (technological segmentation of the functionalities making up the service),
- The infrastructures required by each of the bricks,
- Macroscopic impacts fueled by the choices of mobilization of a functionality or technological building block.

B. Use cases: an illustration of the panorama of possible artificial intelligence applications and services

The use case approach developed in this report aims to provide an illustrative, rather than exhaustive, overview of the possible applications of AI. A list of use cases was constructed to highlight the issues and develop methodological approaches to be replicated by AI service stakeholders when making design choices (R&D, product development, investment direction, etc.) and deployment decisions (purchasing services, public deployment strategy, etc.).

This approach therefore does not cover the diversity of possible technological applications that could fall under the definition of "artificial intelligence", present in all sectors of the economy and among which we can find for example56 :

- Analyses embedded in video surveillance cameras (traffic analysis, behavioural analyses, deployment in public or private spaces, detection of objects or waste in public spaces, etc.);
- Educational conversational assistants (language learning, math, French etc.) through written or verbal interactions;
- Commercial conversational assistants (customer service, simple advice on product identification, support up to the point of purchase based on simple instructions, etc.) in many sectors (insurance, tourism, retail, etc.);
- Content detection tools to assist in moderating platforms and social networks (violent content, AI-generated content, etc.);

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[56] The examples included in this list come from discussions with stakeholders in the sector. The selection was fact, at this stage, of not accompanying them with concrete examples, to avoid highlighting certain marketed solutions over others, the list not being absolutely exhaustive."

- Computer code generation assistants (generation of code in response to specifications, translation from one computer language to another, etc.);

- Tools for modeling and improving high-performance computing capabilities in research and applied sciences (chemistry and pharmacology, materials, climate modeling, etc.);

- Information research assistants within given documentary corpora (administrative procedures, legal corpora, summaries of technical reports, etc.);

- Applications in energy and assistance in piloting electrical systems;

- Industrial applications for predictive maintenance or logistics optimization;

- etc.

Among the possible applications of AI, we find the different categories of digital services in view of their positioning in the context of environmental constraints:

- Applications aimed at reducing environmental impacts (of digital technology itself or other sectors), commonly referred to as "AI for Green", artificial intelligence serving environmental objectives (these objectives are only achieved if the net balance between benefits and environmental impacts of the solution itself is positive);

- Applications aimed at objectives other than environmental objectives: quality of health services, improvement of productivity, efficiency or profitability of certain activities, improvement of the reliability of certain processes, etc.

Within this second category, there are certain applications whose objective is to improve the yields and efficiency of processes directly linked to fossil energy industries and infrastructure. Even if they reduce the unit impacts of fossil fuel processes, these use cases, sometimes referred to as "AI for Brown," cannot be considered "AI for Green" applications (Carbone 4, 2024).

The objective of the work produced here is to question the conditions for the development and deployment of "AI" type technologies compatible with the double carbon constraint; any application falling within a scenario of maintaining fossil fuels is therefore, by construction, not compatible with our scope.

Digital technology, and AI in particular, is a catalyst for the system in which it is integrated (improving efficiency, speed of execution, productivity, etc.). Deploying it without establishing a reference trajectory and benchmark to guide its design and infrastructure will therefore automatically lead to placing AI in a systemic paradigm that increases environmental impacts.

Deploying AI use cases without integrating it into a comprehensive, voluntary, and coherent decarbonization strategy means building an AI that will remain as fossil-based as the economy in which it is placed. This applies both to the resources it will mobilize for its own operation and to the dynamics it will help fuel in the rest of the economy.

II. Energy-climate impact of AI: functional analysis of use cases

A. Use case approach: criteria selected and technological description

Use case selection criteria

The use cases explored in this report have been selected to shed light on key issues related to AI and its infrastructures:

- The "generative AI" phenomenon: what implications does the deployment of generative technology have on the structuring of "AI" services and their energy-climate impacts?
- The direction of innovation: what different combinations of functionalities and technological building blocks (size, infrastructure used, generative or not, etc.) are possible to design an AI service compatible with energy-climate constraints?
- The systemic vision of the digital sector: what are the impacts of AI services on the digital system as a whole (terminals, networks, data centers)?
- The systemic vision of the economy: how do AI services interact with the transformations underway or to be carried out to decarbonize other sectors (mobility, agriculture, etc.)57 ?
- The quantitative vision: how to quantify the energy-carbon impacts of a defined use case, by integrating indirect impacts and the systemic vision into the analysis?

List of selected use cases

Based on these criteria, a list of use cases was selected in order to carry out a qualitative analysis (then, in a second stage, quantitative for one of them):

- Autonomous mobility
  AI technologies for mobility in different environments (spatial complexity, level of connectivity of the area, etc.): urban road (car or public transport/shuttle), non-urban road (truck, agricultural machinery), maritime, rail, air.
- Spreading optimization system Technologies for
  analyzing data collected in growing areas (detection of areas with weaker growth, detection of pests, etc.) in order to monitor and optimize the spreading of fertilizers and pesticides.
- Personal Reporting Assistant
  Assistant (integrated into an application or exchange terminal with voice content) producing reports based on the voice exchanges of users.

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[57] The prism of analysis is above all energy-climate in the context of this work, in order to shed light on the framework linked to this double constraint, to be reconnected with the other planetary limits.

- Online search tool

  Using generative AI as an online information retrieval tool, similar to a search engine.

- Diagnostic assistance tool

  AI image analysis technology, to aid diagnosis in anatomopathology (detection of cancer cells by analysis of sample slides).

- Creative production for advertising spot

  Generative AI technologies within advertising creation services to produce image and video content.

Use cases	Possible technological bricks and levels?	Sector concerned
Personal Reporting Assistant	• Audio content analysis • Content generative technology text • Possibility of different levels of functionality: simple text report, “enrichment” of the report by proposing additional content, intervention of the assistant directly in text or verbal exchanges, live translation on the terminal, etc.	General public, “end-users”
Online search tool	• Content detection and classification for their indexing • Content generative technology text • Integration into search engine algorithmic systems	General public, “end-users”
Creative production for advertising spot	• Generative technology for image and video content	Commerce & Advertising

Autonomous mobility	• Image analysis and recognition and video • Reinforcement learning • Location of computing capacity (edge/ embedded or centralized/ remote)	Transportation
Fertilizer and pesticide spreading optimization system	• Data acquisition: in situ sensors, satellite acquisition, aerial surveys (by drones etc.) • Data analysis: data synthesis, analysis and correlation, image analysis and recognition, etc.	Agriculture
Help tool for medical diagnosis	• Image analysis and recognition • Level of deployment/massification (specific or generalized, number of sites or care services, integration into medical pathways, etc.)	Health

Table 1 - Use cases

B. The "AI Compass": from functional analysis of the use case to the qualification of its effects on energy-climate impacts

The qualitative analysis methodology constructed within the framework of this report aims to answer the following question: what are the conditions of compatibility of an AI service with the energy-carbon constraint?

Economic analysis is in fact not sufficient to know whether a solution is sober or frugal, even when it allows for a reduction in the direct energy consumption of the service: the impact items are not necessarily direct but are on the contrary shared in the infrastructures (networks, data centers, terminal value chains, sensors and electronics). Unit cases are thus rarely large direct emission items: it is the scale of deployment (expected or realized) which structures the national and global infrastructures in their sizing and their impacts and systemic effects are rarely assessed.

So, how can we inform our choices to help fuel energy and climate-sustainable trajectories, as a stakeholder in the design and deployment of services based on AI?

The "AI Compass" presented in this report and the accompanying methodology are intended to enable an informed discussion between three types of stakeholders in the AI service under consideration:

- The strategic and decision-making spheres, which drive the major technological directions (desired functionalities, model and conditions of profitability or relevance of the service, deployment/market launch/purchase scenarios, etc.);
- The technical design spheres, which make technological choices aimed at meeting the major guidelines;
- Technical spheres of environmental impact, capable of carrying out life cycle analysis, conducting quantitative impact studies and/or analysis of compatibility with the sectoral or organizational trajectory.

The Compass allows us to qualitatively reveal the links between the functional choices of a service and the dynamics that its deployment will induce on the digital infrastructures it uses. It offers a reading grid emerging from the application to the specific case of "AI" applications of the four major determinants of the impact of a digital technology:

Does the profitability or relevance of the solution depend on…

- …the generalization of new equipment (sensor, user terminal, etc.)?
- …the multiplication of available computing capacities?
- …the increase in the volume of valuable and/or stored data?
- … the increase in network capacities (bandwidth, coverage, latency)?

C. What are the inflationary factors?

The objective of the work that will follow this interim report will be to build, consolidate and deploy a methodology, the "AI Compass", aimed at linking the choices of functionalities made during design and/or deployment, with the carbon-energy impact trajectories in which these choices can be included. All your comments, criticisms, proposals on the directions taken at this stage, the questions and criteria identified and any leads for relevant interviews to be conducted will be a key ingredient for the continuation of this work!

D. Systemic vision: moving away from the sectoral vision

In this interim report, the analyses presented are mainly focused on the methodology for placing AI services and their functionalities in a systemic vision.

These analyses will however have to be completed, as part of the work leading to the final report, by a recontextualization of these conclusions within a systemic vision:

- At the level of the digital system as such, the dynamics fueled by the services studied create indirect effects on the different third parties of digital (intensification of resource requirements to maintain and secure a complex digital infrastructure, impacts of paradigms and performance of recommendation algorithms on the volumes of content consumed and therefore infrastructure dimensions

in arising) ;

- At the level of the economy as a whole, the impacts of digital solutions influencing the trajectories followed by other sectors (mobility, construction, industry, etc.), directly (carbon surcharge resulting from a new layer of connectivity in a building or infrastructure, for example) or indirectly (rebound effect generated by an AI solution on long-distance mobility uses, for example).

III. Quantification on a use case

In this interim report, only the functional and qualitative analysis was carried out.

Extending this analysis with a quantitative study of one of the selected use cases is one of the objectives of the work to be carried out as part of the production of the final report.

All your comments, criticisms, suggestions on the directions taken at this stage, the questions and criteria identified and any leads or suggestions for sharing feedback or analyses carried out on real cases will be a key ingredient for the continuation of this work!

IV. For “net balance” and systemic approaches

As the analyses have not yet been fully carried out within the framework of this interim report, the consolidated conclusions on the points of vigilance regarding the conditions of relevance of "AI" applications remain to be constructed.

The specifications for a rigorous and well-rounded approach to analyzing the relevance of a digital solution, however, remain valid for artificial intelligence and its applications. The energy-climate relevance of a digital technology must be:

- Systematic: the conditions for the relevance of a solution depend largely on the deployment conditions and choices. There can therefore be no generic answer to the question of the relevance of a digital solution from an energy-carbon point of view: this must be carried out in each specific context before validating its deployment.

- Exhaustive, in "net balance": the energy-climate relevance of a digital solution can only be assessed by taking into account all the impacts linked to its life cycle, including the production phase of the physical media they require (terminals, networks, servers and data centers). A balance sheet that only takes into account direct impacts does not provide any indication of interest from the point of view of physical issues.

- Systemic: the effects and impacts taken into account in assessing the relevance of a solution must include indirect effects (rebound effects, transformation of uses, maintenance needs, etc.). To do without this analysis is to deprive decision-making of a tool that allows deployment choices to be steered by anticipating the deleterious effects that would otherwise dilute the initially planned energy-climate contributions.

This approach allows us to ask questions about the energy-carbon relevance of a solution, up to the very relevance of using digital technology to meet the need.

Applied to AI, this approach is consistent with certain elements of the definition of "frugal AI" formulated by AFNOR (AFNOR, 2024):

"A frugal AI service is therefore a service for which:

- The need to use an AI system rather than another less power-intensive solution to achieve the same objective has been demonstrated;

- Good practices (...) are adopted by the producer, the supplier and the AI client to reduce the environmental impacts of the service using an AI algorithm;

- Uses and needs aim to remain within planetary limits and have been previously questioned.

Recommendations

At the stage of this interim report, we have not established a list of recommendations.

However, we can already say a few words about the need for recommendations on the following topics:

- Climate drift induced by GHG emissions from data centers would require supervision since total emissions continue to increase, moving away from the sector's SBTi commitment and amplifying the consequences of climate change;

- The electricity consumption of data centers will require planning, which is of primary importance, as it can weaken energy and carbon transitions, without being organized;

- Shedding light on future advances in generative AI seems essential. In particular, transparency from service providers and the tracking of impact and consumption data from solutions and data centers is a preliminary and essential ingredient in establishing a coherent systemic direction for digital infrastructures and the systems into which they are integrated.

Finally, our recommendations will be classified into 4 categories, which remain valid for the different components and the different digital uses (The Shift Project, 2023):

- Measurement & transparency,
- Systemic optimization & eco-design,
- Collective reorganization towards sobriety,
- Skills and training.

Conclusions

As this report is an interim report, its production comes halfway through the research and reflection work undertaken since September 2024. The conclusions that we can draw from it are therefore, by nature, provisional and partial.

Furthermore, the lack of transparency of the dominant players in the field of AI, the lack of data availability as well as the more than perfectible documentation of the existing fleet of data centers and new projects, particularly in France and Europe, makes any quantitative assessment of the energy-carbon impacts of the "generative AI phenomenon" difficult, even with regard to direct impacts.

It nevertheless seems possible – and necessary given the speed of propagation of the “generative AI phenomenon” – to deliver a certain number of observations from now on, some of which are also warnings:

- While the energy-carbon footprint of digital technology was already increasing at a sustained rate before the emergence of the "generative AI phenomenon" two years ago, this phenomenon is considerably exacerbating the trend. The large-scale and indiscriminate use of generative AI and large language models to make it a general-purpose technology[58] plays a central role in this. It is therefore urgent to deconstruct a first myth according to which AI would necessarily be generative AI based on gigantic and absolutely versatile foundation models.

- Beyond the harmful effect on the digital footprint itself, the "generative AI phenomenon" constitutes a significant risk – clearly proven in the United States – of imbalance in the electrical system. A risk also identified by the International Energy Agency: the rate of growth of electricity consumption in data centers is becoming much too rapid to respond optimally, whether in terms of transport or electricity production. The expected consequences range from conflicts of use with other sectors (transport, housing, even industry) to the impossibility of maintaining electricity decarbonization trajectories. We must therefore reverse the logic and identify, at least in France and Europe, an energy-carbon budget (and a multi-year trajectory) available for digital technology (including AI) within which the actors' strategies can be developed without fear of neutralizing our common objectives.

- There are decarbonizing digital solutions ("green digital solutions") in the sense defined for example within the European Green Digital Coalition (EGDC, 2024) and there are therefore also use cases where the use of AI can reduce the environmental impacts of a system – under certain contextual conditions and once the reference trajectory to which it is compared has been made explicit. At first glance, however, it seems that the AI used in these use cases is rarely generative AI. In these

[58] “General Purpose Technology”

conditions it is a priori unjustified to claim that the direct environmental costs of the "generative AI phenomenon", which are very real and linked to the use of generative AI, would be overcompensated by indirect gains which, even when they materialize, are not due to generative AI: nothing demonstrates this at this stage.

- AI - and digital technology as a whole - acts as a catalyst. Using it indiscriminately within linear production and consumption methods that still rely substantially on the use of fossil fuels risks leading to an increase in emissions rather than a decrease. The "general framework for frugal AI" developed by AFNOR constitutes an initial response in that it leads to first questioning the use of an AI solution and then responding to the need by mobilizing the least possible technical resources. The "AI Compass" that we are seeking to develop aims to shed light on the issues relating to use cases as early as possible.

There is an urgent need to shed light on the energy-climate issues surrounding the "generative AI phenomenon" with objective data. This report shows that the environmental risks it poses are proven, real, and substantial. It must therefore be the subject of an informed societal debate, especially in France and Europe, where reducing dependence on fossil fuels is coupled with pressing sovereignty issues. We hope that the work initiated in this interim report will contribute to this, while mobilizing the expertise and time of stakeholders in the sector to produce a consolidated analysis and recommendations for the work to come.

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Appendix 1: Data center typology

A data center is a facility dedicated to the centralized hosting, interconnection, and operation of data storage, computing, and transport equipment (ISO, 2021). In addition to these services, these infrastructures typically contain robust power distribution, environmental control, and security systems that ensure the availability of the services it hosts.

This general definition, however, covers several types of data centers that vary in size and function, ranging from small on-premises enterprise data centers, which serve a single organization, to large colocation and hyperscale data centers, which offer shared infrastructure and services for multiple customers on a very large scale. These distinctions are linked to functional differences, depending on (i) their purpose (enterprise, colocation, cohosting, or network operator facilities), (ii) their level of security, (iii) their physical size, and (iv) their hosting mode (mobile, temporary, or permanent buildings). However, it is possible to distinguish a few broad categories of spaces:

- Edge: deployments of micro-data centers, at the edge of the network, geographically close to end users, in order to meet specific demands, often in terms of latency and/or security.
- Enterprise data centers: internal data centers, managed by companies (or public actors) and for their uses, which can vary in size (SME, branch or large company). • Telecommunications service providers: data centers managed by telecommunications companies to support the internal services necessary for the provision of their network services.
- Colocation or co-hosting: Data centers that offer businesses the ability to host their hardware off-site, providing essential power management, cooling, security and networking services[59] .
- Hyperscale: Data centers built by companies that deploy services and service platforms on a very large scale.

More simply, it is possible to distinguish between on-premise (or on-prem) data centers when they are located on the site of the company that uses them, colocation when a third party manages the hosting site, and cloud when the hosting site and servers are managed by a third party.

Although based on distinctions in use, these nuances generally go hand in hand with considerations of surface area. Small data centers have an average surface area of 15 square meters and correspond to edge, SME, or branch data centers.

[59] Note that 61% of colocation service providers host hyperscale tenants in particular (figure 14 (Uptime Intelligence, 2024)).

enterprise. Intermediate sizes include internal data centers (250 square meters) and service provider data centers (650 square meters). Finally, colocation spaces (for an average area of more than 1000 square meters) or hyperscale (for almost 2800 square meters) are considered large-scale.[60]

Since 2010, the distribution between these categories has shifted significantly in favor of colocation and hyperscale centers, increasing from 10% to nearly 80% of the share of servers installed in data centers in the United States in 15 years. This evolution is due to the widespread use of virtualization technologies, which offer great deployment flexibility and respond quickly to changes in computing capacity in the market, often at lower costs. This migration is all the more advantageous because it allows access to specialized hardware, such as modern GPUs, necessary for training and inferencing AI algorithms.

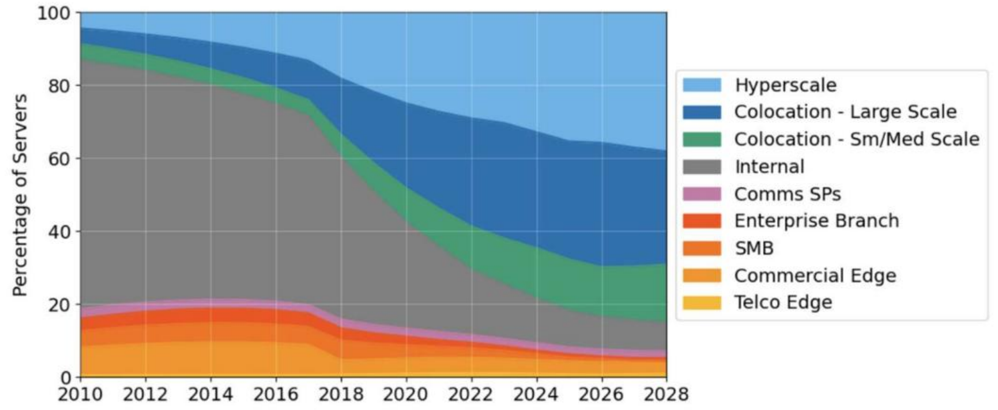

Figure 4.1. Distribution of servers by data center type.

Figure 34 - Distribution of servers by type of data center. Source: (LBNL et al., 2024)

These proportions may vary depending on the geographical areas, the time periods, or the indicator being looked at (number of servers or electricity consumption). For example, if we look at the share of electricity consumption of data centers that are neither colocation nor hyperscale on the total electricity consumption of data centers: Masanet estimated it at the global level at 35% in 2018 (Masanet E. et al., 2020), ADEME estimated it at the French (territorial) level at 52% in 2020 (ADEME & Arcep, 2023), it is projected at the global level to evolve from 21% in 2023 to 5% in 2028 (LBNL et al., 2024) and at the European level to evolve from 40% in 2023 to 22% in 2028 (McKinsey & Company, 2024).

In its prospective study, ADEME-Arcep created categories based on stakeholder types: local public, national public, companies outside of digital players, cloud, HPC, and edge. Compared to the above categories, cloud and HPC are more of the co-hosting or hyperscale type, and the data centers listed in the public sector are of the same type as those of companies.

At the level of a country or a region, it is also possible to separate:

- Data centers installed on its territory: national inventory vision, allowing in particular the identification of territorial resource needs (energy, land, water) and territorial greenhouse gas emissions,

[60] Shehabi, Arman, et al. "2024 United States Data Center Energy Usage Report." (2024)

• Storage and computing capacities associated with the use of services abroad: carbon footprint vision, allowing us to identify the dependencies and climatic impacts of our uses.

Finally, it is also possible to classify them by objectives (versatile or specialized), by business models (on-prem, colocation, cloud), and on other criteria (performance, fault tolerance) (FS blog, 2024).

Data centers have as their main energy consumption items (i) the loads of its IT equipment, (ii) those of the cooling and environmental control equipment, and (iii) the internal power conditioning system, as well as the security, lighting and office equipment. The power supply of a data center is subject to continuity constraints, with emergency power systems, in the event of failure of the main power system, in order to prevent service interruptions.

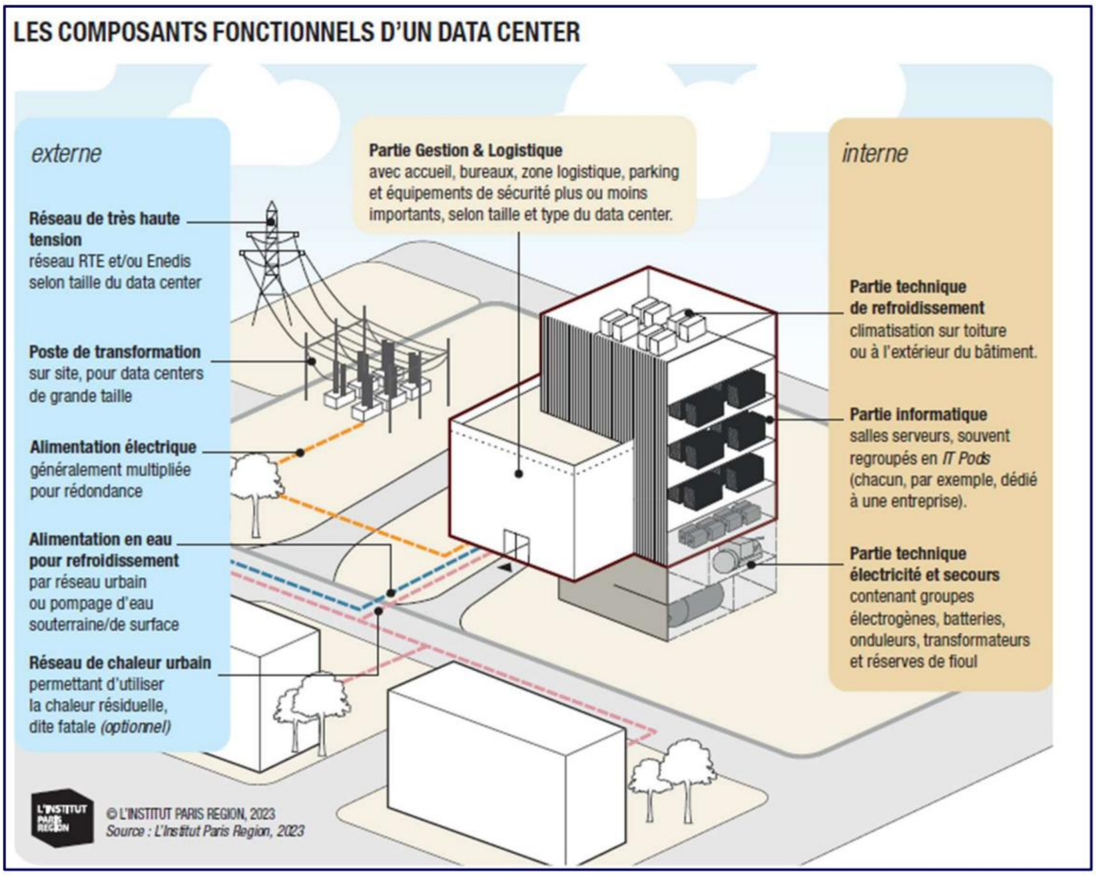

Figure 35 - The functional components of a data center. Source: (Paris Region Institute, 2023)

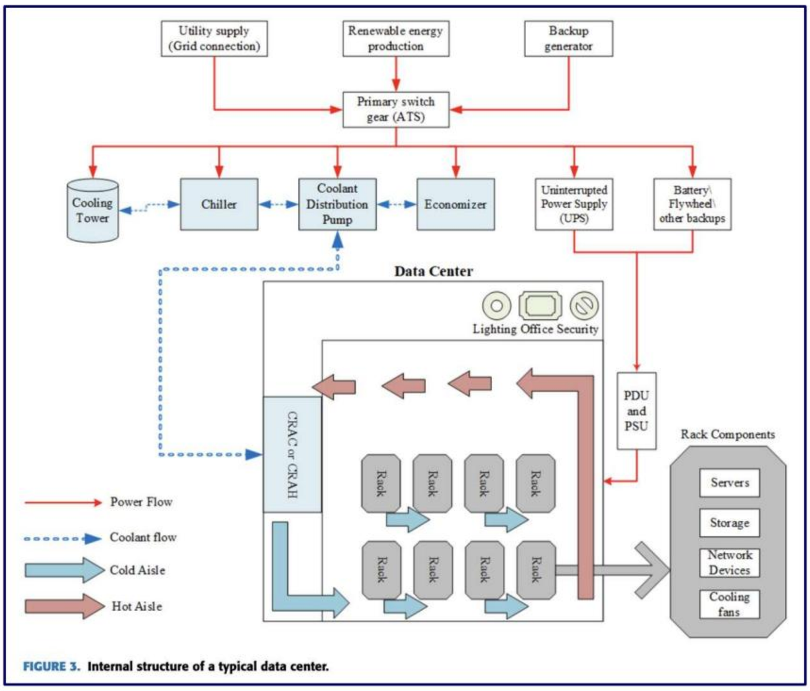

Figure 36 - Structure of a data center. Source: (Ahmed MU et al., 2021)

A data center's consumption depends on the consumption of its IT equipment and its cooling system. Therefore, the energy efficiency of a facility is measured by its power usage effectiveness (PUE), defined as the total energy consumption of the data center divided by the consumption of its IT equipment. The closer this index is to 1, the more efficient the data center, because it uses less energy for its auxiliary functions (cooling, power conditioning, lighting, etc.). In 2024, the global average PUE will be around 1.5, although there are regional and temporal disparities. This factor mainly depends on the cooling systems used (related to the modernity of the infrastructure), and the climate in which the data center is located (Ahmed, 2021).

Regarding PUE, several areas need improvement: several aspects require improvement: although a calculation standard exists (ISO/IEC 30134-2:2016), standardization remains insufficient, with a lack of transparency regarding the assumptions and definitions used. Taking into account “idle” consumption in particular is one of the areas for improvement. Finally, as with any efficiency indicator, it is important to consider that increasing volume artificially improves this indicator.

Data centers can be equipped with renewable energy sources to supplement the perceived power of the local grid. There are grid interconnection issues (Gnibga W. et al., 2023). They can also subscribe to greener energy contracts to improve their emissions reporting. However, it is important to remember the difference between location-based emissions, which follow the electricity grid averages in a specified location, and market-based emissions, which concern contracted energy purchased, such as renewable energy from a supplier outside the main utility provider in a region. These attribution standards can be misleading in emissions reporting, as market-based emissions are generally lowered by lower carbon intensity values.

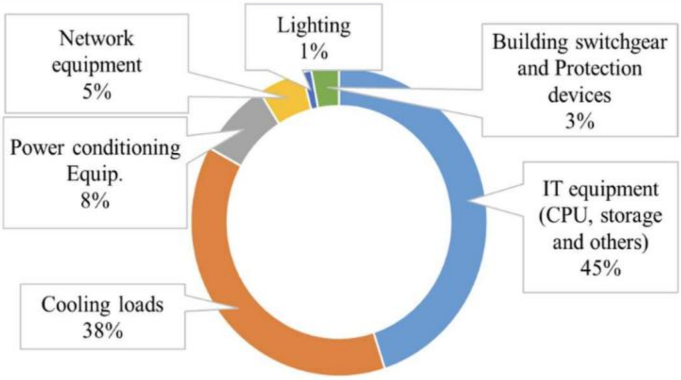

FIGURE 4. Analysis of power consumption proportionality in data center. [8], [24].

Figure 37 - Distribution of electricity consumption of a data center. Source: (Ahmed MU et al., 2021)

Finally, in terms of carbon footprint, the distributions can be different; Schneider Electric offers a breakdown for a typical data center61 (Schneider Electric, 2023)62 , highlighting the major part of scope 3, including the on-board footprint.

Step	Carbon focus	Findings	Proposed actions
1	Total carbon	• Scope 3 represents 38-69% • Electricity has a Scope 3 component	• Use more renewable/clean energy
2	Scope 3 emissions	• Capital goods represents 46-71% • Fuel- and energy-related activities represents 13-47% • Core & shell represents a small percentage	• Purchase low carbon capital goods • Use more renewable/clean energy
3	Embodied carbon	• Manufacturing represents ~ 90% • IT represents 57-83% • Facility infrastructure represents 17-43%	• Extend server lifespans • Design and operate for high utilization from IT to the facility • Optimize IT demand
4	Facility infrastructure embodied car-bon	• Power system represents ~ 30% • Cooling system represents ~ 30% • Core & shell represents 8-15%	• Purchase efficient and low carbon products • Reuse existing building for data centers in-stead of new construction
5	Sub-system embodied car-bon	• Concrete represents 85% • LV switchgear represents ~ 30% • VRLA battery represents 6-21% • Air-cooled chiller represents ~50%	• Evaluate modular and prefabricated construc-tion methods • Purchase efficient and low carbon products

Figure 38 - Distribution of the impacts of the "Scope 3 Embedded Footprint" of a data center. Source: (Schneider Electric, 2023)

[61] Which has the following characteristics: 1 MW, 50% load, 6 kW / rack, PUE of 1.34, emission factor of US electricity, 5 tCO2e/kW of IT onboard footprint, 94% storage servers and 6% network equipment, 50% populated. But with the ability to vary these characteristics in an online simulator https://www.se.com/ww/en/work/solutions/system/s1/data-center-and-network-systems/trade-off-tools/data-center-lifecycle-co2e-calculator/

[62] Schneider Electric. (2023). Quantifying Data Center Scope 3 GHG Emissions to Prioritize Reduction Efforts—White Paper 99. https://www.se.com/ww/en/download/document/SPD_WP99_EN/

To target sustainable purchases in data centers and computer servers, U4E, in consultation with stakeholders such as Uptime Institute, France Datacenter, L'Alliance Française des Industries du Numérique, EQUINIX, GIMELEC, Google, Microsoft, LBNL, IBM Corporation, establishes guidelines recommending the monitoring of the following indicators (Figure 39), provides objectives (Figure 40) and establishes a score based on these indicators (Figure 41) (U4E et al., 2025)63 .

Portée du contenu de la directive

Critères de performance pour les centres de données et les serveurs informatiques

- ✓Efficacité énergétique (PUE)
- ✓Efficacité de l'utilisation de l'eau (WUE)
- ✓Efficacité du refroidissement (CER)
- ✓Efficacité énergétique des équipements informatiques pour les serveurs
- ✓Efficacité du serveur
- ✓Efficacité du stockage
- ✓Efficacité de l'alimentation électrique (UPS)
- ✓Efficacité en état de veille

Conditions de fonctionnement

- ✓ Localisation des centres de données
- ✓Ratio d'énergie renouvelable (REF)
- ✓Résilience des centres de données
- ✓Modularité
- ✓Conception du refroidissement
- ✓Plage de température et d'humidité de fonctionnement pour les serveurs
- ✓Critères de gestion de l'alimentation du processeur
- ✓Taux d'utilisation des serveurs (ITEUsv)

- **Autres aspects : éclairage, moteurs, réfrigérant utilisé pour le refroidissement, transformateurs**

Figure 39 - U4E Directive indicators. Source: (U4E et al., 2025)

Valeurs des indicateurs clés (KPI)

		2025	2027	2029	2031
Centre de données de colocation existant pour héberger les données	**PUE**	≤ 1,5 HH : ≤ 1,7	≤ 1,4 HH : ≤ 1,6	≤ 1,3 HH : ≤ 1,5	≤ 1,2 HH : ≤ 1,4
	WUE	≤ 1,5 L/kWh	≤ 1 L/kWh	≤ 0,5 L/kWh	≤ 0,2 L/kWh
	RÉF	≥ 50 %	≥ 60 %	≥ 70 %	≥ 80 %
	CER	≥ 2,5	≥ 2,9	≥ 3,8	≥ 5,7
	ITEUsv	≥ 50 %	≥ 60 %	≥ 70 %	≥ 80 %
Nouveau bâtiment du centre de données - By design / après 3 ans de fonctionnement	**PUE**	≤ 1,4 / ≤ 1,5 HH : ≤ 1,6 / ≤ 1,7	≤ 1,3 / ≤ 1,4 HH : ≤ 1,5 / ≤ 1,6	≤ 1,2 / ≤ 1,3 HH : ≤ 1,4 / ≤ 1,5	≤ 1,1 / ≤ 1,2 HH : ≤ 1,3 / ≤ 1,4
	WUE	≤ 1,5 L/kWh	≤ 1 L/kWh	≤ 0,5 L/kWh	≤ 0,2 L/kWh
	RÉF	≥ 50 %	≥ 60 %	≥ 70 %	≥ 80 %
	CER	≥ 2,9 / ≥ 2,5	≥ 3,8 / ≥ 2,9	≥ 5,7 / ≥ 3,8	≥ 10 / ≥ 5,7
	ITEUsv après 3 ans	≥ 50 %	≥ 60 %	≥ 70 %	≥ 80 %

HH : Climat chaud et humide (zones climatiques ASHRAE 0A, 1A, 2A, 3A)

Figure 40 - Values of the U4E directive indicators. Source: (U4E et al., 2025)

[63] U4E, United for Efficiency, & UN Environment Programme. (2025). High-Performance Data Centers and Servers for Sustainable Market Transformation. https://united4efficiency.org/wp-content/uploads/2025/02/U4E-for-AI-Summit_FR_7Feb25-1.pdf

Indicateurs de performance clés	Points	Pondération
Gestion de l'énergie **(PUE)**	De 2 à 1,2 noté sur 5 points	30 %
Efficacité du refroidissement **(CER)**	De 2,5 à 10 noté sur 5 points	20 %
Consommation d'eau **(WUE)**	De 2 à 1,2 L/kWh noté sur 5 points	20 %
Ratio d'énergie renouvelable **(REF)**	De 50% à 90% noté sur 5 points	20 %
Taux d'utilisation des serveurs : **taux d'utilisation des serveurs (ITEUsv)**	De 30% à 70% noté sur 5 points	10 %

Figure 41 - Rating system proposed in the U4E directive. Source: (U4E et al., 2025)

Appendix 2: A first calculation: “What carbon footprint for global data center projects?”

This appendix refers to the “GHG Calculator from TWh” tab in the “PROVISIONAL VERSION - World Status.xlsx” file.

Calculation :

In this one, based on an estimate in TWh, we propose to calculate greenhouse gas emissions. This first calculation, very simple, is based on:

• Taking into account the carbon intensity of electricity, • A ratio to estimate the on-board carbon footprint of data centers from their electricity consumption.

Hypotheses:

The electricity emission factor considered is the global emission factor: 460 gCO2e/kWh in 2022 (Stated Policies) (IEA, 2024b) and 312 gCO2e/kWh in 2030. This assumption for 2030 is questionable since the growth of data centers requires electricity consumption, often unanticipated, which could be carbon-based (Figure 4.1 in (IEA, 2024b)). Furthermore, on each electricity transmission network, the electricity emission factors are different and each data center can have a displayed emission factor (thanks to the purchase of PPAs) or an actual emission factor different from that of the network. This choice of a global average value makes it possible to reflect the impact of data centers given current global electricity production capacities.

In order to take into account the on-board carbon footprint, we assumed that the on-board carbon footprint represented 35% of the carbon footprint of use based on some macro figures: ~26%64 (Data Center Dynamics, 2024a), ~32% (Malmodin J. et al., 2023)65, ~35%66 (Schneider Electric, 2023).

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[64] Lescuyer figure for data centers in Europe considering a lifespan of 20 years.
[65] From the on-board footprint of 30 MtCO2e and the total footprint of 95 MtCO2e (p9 of the publication, need the Supplement to the publication to give more details on the assumptions).
[66] Figures obtained for a data center of: 1 MW, 50% load, 6 kW / rack, PUE of 1.34, emission factor of US electricity, 5 tCO2e/kW of IT onboard footprint, 94% storage servers and 6% network equipment, 50% populated. But with the ability to vary these characteristics in an online simulator https://www.se.com/ww/en/work/solutions/system/s1/data-center-and-network-systems/trade-off-tools/data-center-lifecycle-co2e-calculator/

Appendix 3: Carrying out and/ or interpreting an estimate of the electricity consumption of data centers: what questions should be asked?

This appendix is intended to reinforce and detail the questions in the paragraph “Evaluation of electricity consumption and putting it into perspective”.

It is essentially methodological in the sense that it allows us to share questions that we believe we have only partially clarified today and which highlight uncertainties that can explain significant differences from one study to another.

It is accompanied by the "GHG Trajectory from GW" tab in the "PROVISIONAL VERSION - World Status.xlsx" file to allow familiarization with these questions. This tab is not a calculator but rather a tool for reflection and simulation, at least to date.

Projecting the electricity consumption of data centers over a horizon of a few years can be done based on knowledge of the demand for electrical power 67 to be installed (GW) from existing sites and projects at different stages of maturity.
Indeed, a data center project takes 2 to 5 years to become operational.

For this exercise, let's take for example the data provided in the DCByte report (DCByte, 2024). These aggregate:

1. IT power installation requests 2. For nearly 7,000 data centers 3. Across the globe, with fragmented data for Russia and China 4. From market analyses, satellite observation images, press releases, interviews, physical inspections

5. Evolution histories for each of these 3 categories:

- Projects in the operational phase: these are the projects for which the IT power is already deployed, whether rented or not.

67 Other methods are possible, based for example on historical and forecast estimates of IT equipment fleets and deliveries (servers, storage bays, etc.), which we will not discuss here at this stage.

• Projects in the order books: these are both projects currently being deployed and secure projects, i.e. those on which confidence is high with accepted elements such as land and power.
• “Early phase” projects: these are those that have been announced or those on which there is speculation but which do not secure all the required elements (land, power, etc.).

These 5 points are all points of attention since:

1. The historical data, project lists, and projections can be in IT power (the electrical power of the installed IT capacities) or in total electrical power for the entire data center, including the environment necessary for the proper functioning of IT (equipment for cooling the servers in particular). In this case, the energy consumption of the environment would be added or not, which can constitute up to 50% of IT consumption in nominal operation and much more in the ramp-up phase. In this report, the estimates are in IT power.

2. The number of data centers and/or the type of data centers considered gives an indication of the scope considered: with 7,000 data centers out of approximately 12,000 worldwide in this report, only a part is covered. But is that really a big deal? It depends on the question these estimates are trying to answer: to provide information on the state of the market related to the two largest categories of data centers (hyperscalers and colocation)? Or to estimate the electricity production capacities required to power all of the world's IT capacities?
3. The geographical scope is also important for the same reasons. In the majority of reports, the China scope is never detailed and is often referred to as "partial." With or without this, the estimate is off by around 25-30%. The same goes for countries where the data center industry is emerging, and which are not always represented even though growth in the coming years could be very strong.
4. The question of the construction and reliability of primary data. In this report, the methodology for constructing the data provides (some) information on the reliability to be given to "early phase" projects, for example.
5. Understanding the different project maturities can be relevant to understanding when electricity consumption demands will actually occur and possibly modeling commissioning and ramp-up times.

Then, based on an IT power demand scenario, different profiles must be considered:

• A load profile. Knowing that several phenomena overlap: for data centers already installed, it is possible that the load rate68 will improve.
For data centers being installed, they are lightly loaded at startup. • A PUE profile.
Again, several phenomena overlap: PUE being an efficiency indicator, it decreases with volume (when data centers fill up). At opening, PUEs are poor for several years.

68 The load rate that interests us here will be the average percentage of use of the electrical power of the installed IT; this results (without being proportional) from the IT load rate, that is to say the average percentage of the computing power used.

To go as far as calculating greenhouse gas emissions, this is completed by:

A carbon intensity profile of electricity, a way of taking into account on-board emissions.

To date, the values in the “GHG trajectory from GW” tab in the “PROVISIONAL VERSION - World Status.xlsx” file are simply indicative, to open the discussion on precisely:

• Modeling, • Data selection, • The interest of carrying out this reasoning by type of geographical area or by type of data centers to adjust certain values.

Your contributions during workshop #1, or by return email, will be invaluable.

Appendix 4: Cryptocurrencies, a use of digital infrastructure still present?

Cryptocurrency transactions rely on public blockchains, decentralized platforms that allow anyone to track transactions (from/to encrypted accounts) and also to participate in securing this mechanism. To gain the right to validate transactions—and be rewarded with newly created currency—competitions between validators take place each time a block of transactions is validated.

Mainly, two types of mechanisms dominate:

- Proof of Work (PoW) involves mobilizing computing power to be the first to solve a given mathematical problem. The infrastructures used include, for example, server farms equipped with specialized cards (ASIC/GPU). This is the mechanism behind Bitcoin, the largest asset in terms of capitalization.
- Proof of Stake (PoS) relies on staking one's cryptocurrency assets for a chance to win validation rights. This is the mechanism behind Ethereum, the second-largest asset in terms of market capitalization.

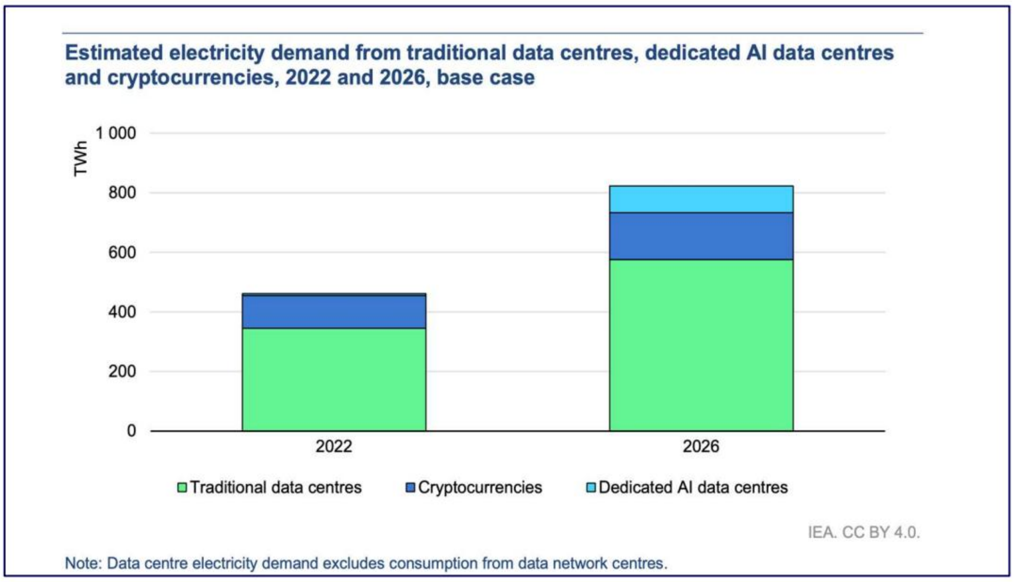


Figure 42 - Estimated electricity consumption for data centers worldwide. Source: (IEA, 2024a), p. 35

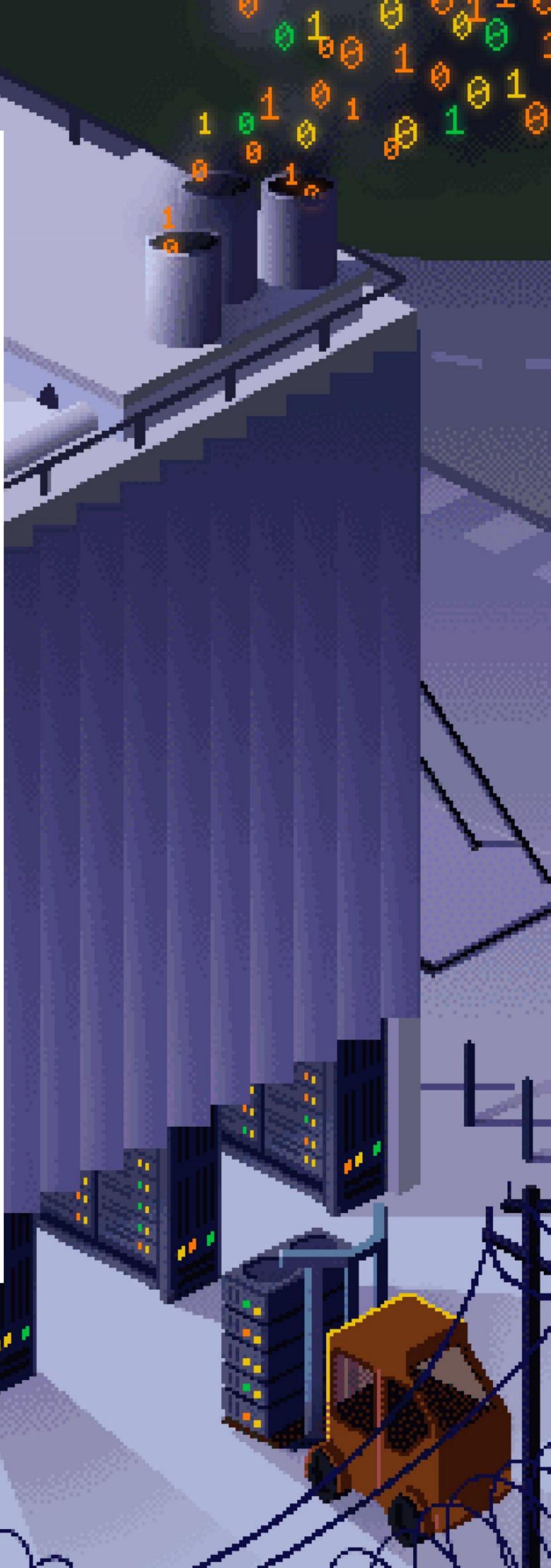
It is the "Proof of Work" mechanism that represents the vast majority of the electricity consumption of cryptocurrencies: 120 TWh out of the 130 TWh of total consumption of cryptocurrencies in 2023 (IEA, 2024a) (University of Cambridge, 2025).

Historically, the growth of this consumption is uninterrupted (IEA, 2024a) (University of Cambridge, 2025), fueled by two factors: the improvement in the performance and efficiency of computing cards, as well as the number of competing miners69. Its territorial distribution in the world will, however, depend on the dynamics instilled in the computing infrastructures dedicated to it: availability of computing resources, availability of electricity, regulations and public policies accompanying, supervising and authorizing/prohibiting their implementation. Today, a country like France is not directly exposed to these infrastructure issues, unlike the United States70, but the effects of competition and availability of resources for data centers and their implementation could influence their future distribution.

[69] The number of miners is at least partly correlated with the price of bitcoin and the cost of electricity, a key factor in the economic models of this activity (Berkeley, 2024).

[70] France represents 0.21% of the total global hashrate, or approximately 360 MWh/year; the United States, 37.84%. (University of Cambridge, 2025b).

THE SHIFT PROJECT



The Shift Project is a think tank working toward a post-carbon economy. A non-profit organization recognized as being of general interest and guided by the requirement of scientific rigor, our mission is to inform and influence the debate on the energy transition in Europe. The exponential growth of digital technology, and how this development can interact with our societies' decarbonization goals, constitutes one of the key aspects of the carbon transition.

Our members are large companies that want to make the energy transition their priority.

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