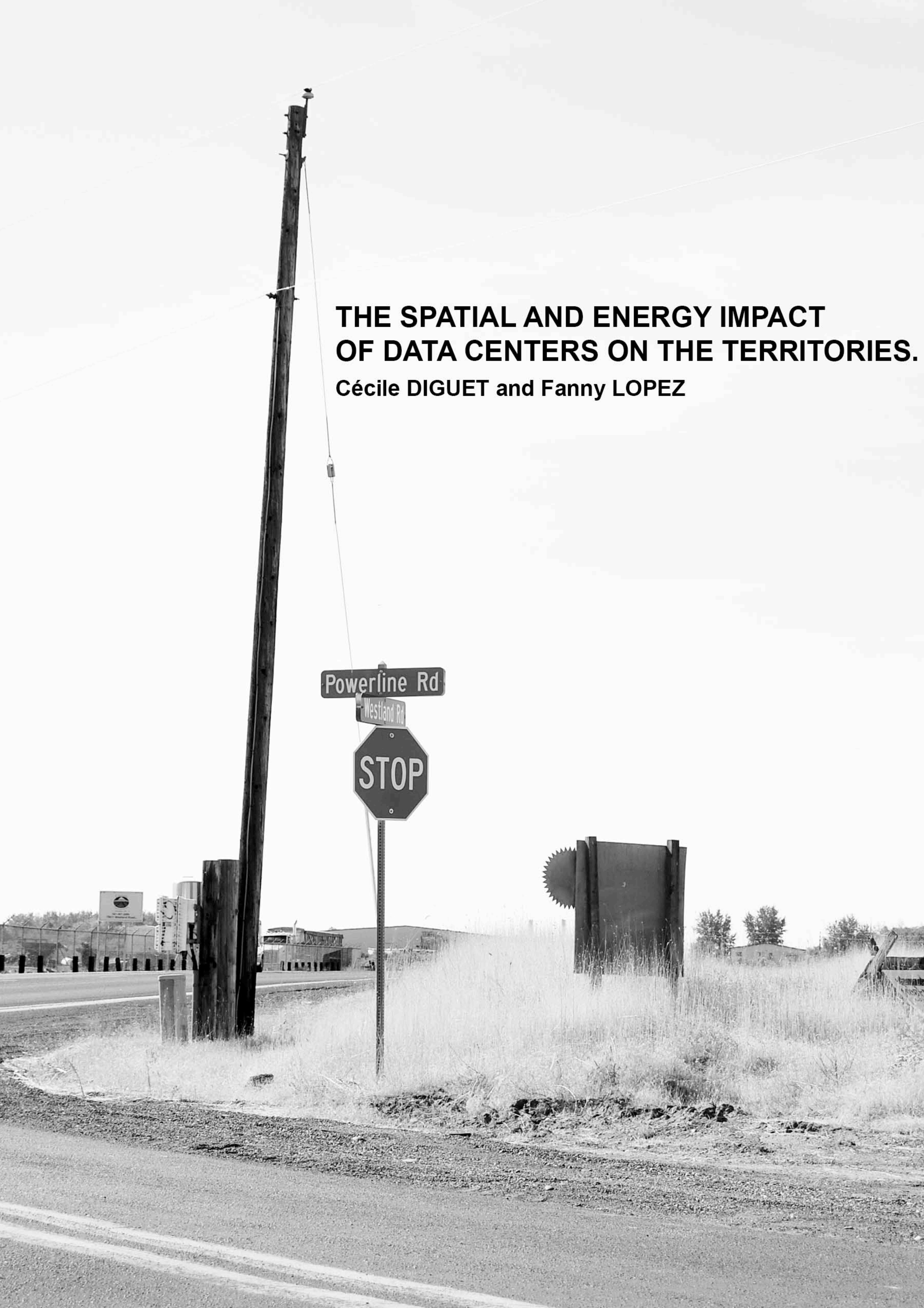
THE SPATIAL AND ENERGY IMPACT OF DATA CENTERS ON THE TERRITORIES.

Cécile DIGUET and Fanny LOPEZ



EXPERTISES

APRIL 2019

THE SPATIAL AND ENERGY IMPACT OF DATA CENTERS ON THE TERRITORIES.

Cécile DIGUET and Fanny LOPEZ
With Laurent Lefevre

ENERNUM Project

ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie

In partnership with: Caisse des Dépôts Groupe Institut pour la recherche; Fondation Tuck The Future of Energy; IAU Institut d'Aménagement et d'Urbanisme îledeFrance; Éa v&t; Inria inventeurs du monde numérique

CITATION OF THIS REPORT

Cécile Diguet and Fanny Lopez, *The spatial and energy impact of data centers on the territories*, ADEME Report, 2019. Synthesis.

Online www.ademe.fr/mediatheque

This document is distributed by the ADEME

20, avenue du Grésillé
BP 90406 | 49004 Angers Cedex 01

Contract number: 1717C00015

Study directed and written by Cécile Diguet and Fanny Lopez.
cecile.diguet@iau-idf.fr
fanny.lopez@marnelavallee.archi.fr

With the support of Laurent Levevre (Inria, Université de Lyon) et Rémi Louvencourt (Eavt).

Call for research projects: APR Energie Durable 2017

This project was co-funded by the ADEME, the Institut de Recherche CDC and the Tuck Foundation.

Technical coordination - ADEME : Solène Marry

TABLE OF CONTENTS

Abstract

The spatial and energy impact of data centers is becoming more and more impacting for territories, given the unprecedented and massive growth of data creation and exchanges, leading to large storage needs. Data centers are very diverse in size, use, stakeholders and sitings. This makes the understanding of their dynamics and spatial effects complex.

This report aims at describing the data center landscape in France and in three locations in the United States, each being representative of different spatial and energy situations (rural, suburban, urban).

They are potentially disruptive of local energy systems, and their accumulation in urban areas as their spreading in rural ones are a concern for urban and regional planning. Data centers are thoroughly analyzed here to better apprehend how new digital territories emerge, how energy solidarities can be built and new governances implemented.

There is a specific focus on alternative digital infrastructures that have been developing, both in Africa, South America and in the less connected territories of Europe and the United States. Dedicated to both Internet access and, increasingly, to hosting services, they are a distributed, peer-to-peer response whose environmental impact seems ultimately more limited than the centralized and large-scale infrastructures, because they are calibrated closer to the users' needs. They also appear more resilient to climate events and computing attacks because less technically centralized and less spatially concentrated.

They are therefore an option to consider and support, but also to better evaluate, to reduce the spatial and energy impacts of data centers.

The report presents prospective visions of three possible digital worlds, based on global trends and emerging signals: "Growth and digital ultra-centralization;" "Stabilization of the Digital Technical System and infrastructural diversity: a quest for a difficult resilience;" "Digital ultra-decentralization: the end of data centers?"

Recommendations for France context are finally proposed around three tracks: actors and governance; urbanism and environment; energy. Research subjects to develop further are also presented.

Introduction: the illusion of infinity and the finitude of resources

The growing production of digital data implies the deployment of a dedicated infrastructure for processing, storage and switching flows. These are data centers. This infrastructure is itself supported by the electricity infrastructure that is at the heart of its business model and functioning. Carried by the explosion of data exchanges, the cloud and connected objects, data centers will be among the most important electricity consumption elements of the 21st century.

A new phase of the networks urbanism, the smart city[1] is often analyzed in terms of uses and practices, services and events, leaving in the background the physicality and energy impact of its infrastructures. In fact, urban planners and developers rarely include this question in their reflections. On one hand, developer and operators of data centers develop a broad typological panel: secured, standardized and flexible “boxes”; signal architectures on high-tech campuses; transformed buildings such as former telecom edifices, bunkers, office buildings or industrial sites. They can be found everywhere in the city center, in the suburban zones, in rural territories. Whether they are completely autonomous in energy use or incorporated into exchange circles of variable scopes (block, district, city, territory), they redefine, each time, the energy project of the places in which they are sited.

The proposal of data centers that are efficient in energy consumption has been studied for a dozen years, after the first work of the researchers at Virginia Tech on the GreenDestiny cluster. Many challenges have been raised on more efficient cooling systems (cold or warm water cooling, free cooling, etc.), on more efficient digital structures (servers, storage bays, network equipment). It is also useful to design digital equipment capable of showing electricity consumption proportional to their workload. Lastly, parallel to these material advances, the design of software services improving their energy footprint (software eco-design) is a major project being explored in academic and industrial research. In France, the academic research being conducted by the Inria, the CNRS, the CEA and different universities makes it possible to approach some of these sectors. Data centers in France are relatively regulated as industrial objects: ICPE authorizations; some are “Operators of Vital Importance” (OIV); there are injunctions on energy efficiency through the European Code of Conduct for energy efficiency in data centers (recently revised): there are the American standards ASHRAE 90.4 (See Annexes for more details). But if energy efficiency on the scale of the building is an area that has been studied and partially applied, questions on the urban integration and architectural potentialities of these objects has been little analyzed, even underestimated, in the same way as a more eco-systemic reflection that would make it possible to better insert data centers into local energy systems.

No urban planning and digital planning document in France (SCORAN, SDAN, SDUS, SCOT…) proposes a global understanding of the spatial and programmatic phenomenon, even if elements that take the phenomenon into account are found in the Île-de-France Regional Plan for Climate, Air and Energy (SRCAE) or in the Paris Metropolis Plan for Climate, Air and Energy (PCAEM). How can the integration of these new factories be analyzed in the scenarios of intermittent energy provision based on renewable energies with a possible link to smart cities? Is a more eco-systemic integration of these objects whose governance and regulation modalities mostly elude urban planning actors possible?

[1] See the work by Antoine Picon on the subject, notably: *Smart Cities A Spatialised Intelligence*, Wiley, 2015.

By the yardstick of a pioneering and flourishing American digital industry, but with a weakened energy system, field studies on the West Coast (Oregon, Silicon Valley) and the East Coast (New York) have enabled us to shed light on the challenge of integrating data centers into territorial energy systems. We have completed these areas by meetings in Barcelona with associative actors of digital infrastructures (notably Guifi.net) and in Stockholm, to deepen our knowledge of the combined “land, energy, data centers” strategy of the city.

In the Île-de-France, we particularly examined the case of Plaine Commune, a historic siting territory for colocation data centers, and the Saclay plateau, a research and development cluster whose data processing is at the heart of its functioning.

The challenges taken up through this research are threefold and dialogue with each other:

- Energy sobriety and the use of renewable energies;
- The integration of data centers into local systems via pooling, exchanges, connections and less infrastructural redundancy;
- The architecture and spatial integration of these infrastructures in the cities and territories.

The research presented here proposes elements to understand, know and decode both the data center object but also its interactions with the environments in which it is inserted in its architectural and urban dimensions, in liaison with energy, economic and governance issues. It describes the complex territorial and energy situations in which data centers are inserted, and takes stock of the diversity of the data center object, the dynamics that their installations create in urban, suburban and rural zones, good practices in terms of energy pooling, urban and architectural integration and governance, all showing the limits and curbs on an integration of data centers in a more eco-systemic functioning.

The report explores the potentials of citizen and peer-to-peer digital infrastructures and original integrated approaches for data centers, in Red Hook (Brooklyn, New York) and Stockholm (Sweden). It next focuses on more prospective horizons to illustrate the digital future possible connected to major fundamental trends: the climate and energy crisis, digital overconsumption, the urbanization of the world and the geopolitics of storage.

Lastly, tracks for work, organization, innovation and recommendations to improve the integration of these strategic digital structures, linked to this industry’s rapid mutations, are proposed.

1. The digital infrastructure: a growing footprint on the territories

The Internet is an infrastructure composed of three principal elements:

- Networks (optical fiber, copper networks, wireless networks);
- Data storage centers (data centers);
- User terminals (smartphones, computers, tablets, connected objects, etc.).

The network is comprised of optical fiber and copper cables, going through trenches under sidewalks, roads, along high-voltage lines, or along metro tracks, train tracks, on the shoulders of highways and on the seabed. The network is also based on dedicated telecom equipment like routers and switches, physical spaces like meet-me-rooms and Internet Exchange Points.
These spaces are strongly linked to another strategic Internet infrastructure, data centers, whose continuous service is central for the functioning of the digital world as they store, process and distribute digital data. Redundancy is at the center of their organization: copy of data on several sites, duplication of electricity infrastructures in the event of a breakdown, water tanks in case of a cutoff for air-conditioning…

Data centers were created in the 1990s due to several factors, notably:

- The explosion of the commercial Web;
- The deregulation of the telecom market;
- The replacement of “mainframe” systems by server systems.

A data center is defined as a hosting building that receives a group of digital infrastructures (data computing, storage and transmission equipment). The data center has cooling and heat recover systems as well as backup equipment: batteries, UPS, generators. A data center can contain different technologies depending on application needs, for example, computing servers for high-performance calculation centers, storage bays for data centers or network equipment for telecom operator centers (like meet-me-rooms in which all the telecom operators are connected to each other).

There are different types of data centers and uses can vary.

- Operation, corporate or ministry data centers for example, host and manage their own data servers in a building reserved for them.

- In infrastructure or colocation data centers, different uses are possible:
    - Hosting of digital equipment for corporate clients (the operator supplies the space and the electricity, which is called power and shell).
    - Availability of servers and IT equipment by the hosting service provider for its clients, also called bare-metal provisioning. The clients can make physical temporary reservations of the server, the disk array or the network equipment to benefit from a guaranteed use that is not shared of the infrastructures.
    - Reservation in Cloud mode: the clients can reserve virtual machines on the data centers' servers.

The digital acceleration currently underway, notably with the very strong development of Cloud services, has led to the continuous creation of new data centers throughout the world. The Natural Resource Defense Council estimated that, in 2014, 12 million servers were necessary in American data centers to support all the digital activities.[2] The number of very large data centers should increase from 338 in 2016 to 628 in 2021.[3] Nevertheless, we observe for example in the United States that the electricity consumption of data centers had a tendency to increase somewhat slower during the 2010-2014 period (compared to the 24% increase during the 2005-2010 period). An increase of about 4% is expected over

---

[2] Cisco, 2018, *Global Cloud Index: Forecast and Methodology*, *2016-2021*. https://www. cisco.com/c/en/us/solutions/collateral/service- provider/global-cloud-index-gci/white-paper-c11- 738085.html
[3] Whitney Josh / Anthesis and Delforge Pierre /NRDC, 2018, *Data Center Efficiency Assessment*. https://www.nrdc.org/sites/default/files/data- center-efficiency-assessment-IP.pdf

the 2015-2020 period.[4] The history of the consideration of the digital's environmental impact sheds light on the situation today.

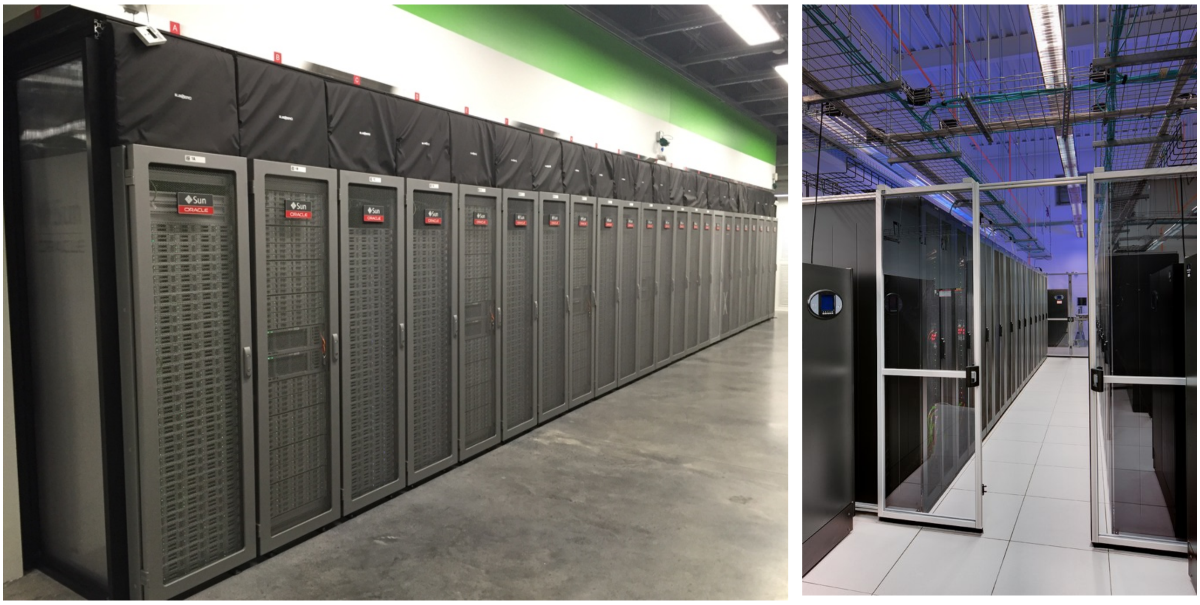


Figure 1. Interior of an Oracle data center and that of the Cleveland clinic designed by the Gensler agency. Credits=© 2016.

1.1 A major environmental impact

The digital and the environment from the viewpoint of history

The first work on the environmental and energy impact of information and communication technologies appeared at the very beginning of the 2000s. We can hypothesize that the cybernetic world had not anticipated the energy impact of the embryonic Internet because their computer technology was not necessarily based on the massification of the production and use of personal data (with the whole consumer dimension that this now implies). But this was also due to a technological enthusiasm that allowed them to believe that technology would also solve this problem.

In the early 2000s, the emergence and development of the Internet for the general public, the first social networks and the smart city would take part in a change of paradigm. The massification of the production of data and their use for commercial purposes would require new large-scale management questioning the costs and performance of the infrastructure that existed until this point. The idea of the smart city was then created by the industrialists and engineers at Cisco and IBM, between 2004 and 2008, through a research and marketing program as powerful as it was effective. While the economic crisis was affecting the United States, the IT giants launched a global infrastructural product that has continued to dominate the economic and urban prospective. The utopia of the "reactive environment" that originated in the 1970s consequently proposed to rely on machines to optimize and increase, calibrate and regulate the urban project in its systemic dimensions. But this fervor largely underestimated the physicality, materiality and energy impact of the phenomenon.

Since the very beginning of the history of information science, the focus on speed as a central measurement of performance was touted to the detriment of other measurements like energy efficiency, whereas it did not impact costs. The data center community realized that it needed energy efficiency for high-performance computing, at the moment when, in 2008, annual energy costs for a data center exceeded the annual purchase cost of the servers.

[4] Shehabi Arman, Josephine Sarah, Sartor Dale A., Brown Richard E., Herrlin Magnus, G. Koomey Jonathan, Masanet Eric R., Nathaniel Horner, Inês Lima Azevedo, William Lintner, *United States Data Center Energy Usage Report*, Lawrence Berkeley National Laboratory, LBNL-1005775, 2016.

The problem of energy and resources in data centers

The components of data centers as well as the energy required for their operation raises questions on energy efficiency and sobriety:

- Rare metals and life cycle
  Like all industrial products, digital equipment follows a five-phase life cycle: mining of resources (metals and rare earths,[5] silica) required for their production, the design of equipment (often in Asia), their transport to users (by boat, plane or truck), the usage phase and the end of life of the equipment (repairs, recycling, burying). Each of these phases generates various environmental impacts with, among others, primary energy consumption, water consumption, toxicity and pollution (of the air, water and soil), generation of greenhouse gases, etc.

- Very energy-hungry cooling infrastructures
  The cooling system often represents 50% of a data center's electricity consumption. It therefore comprises a major R&D area, and an energy performance vector via free cooling, water cooling or geo cooling.

- Equipment redundancy for problem recovery (or backup)
  Battery rooms, like backup generators, occupy a fair amount of space in a data center, for a very infrequent use (apart from monthly tests). They are therefore above all dormant infrastructures. Backup generators run on diesel oil and cause air and sound pollution. The sites have large tanks of diesel oil to supply them.

- Oversupplied server rooms:
  In 2015, the Uptime institute conducted a study on North American data centers that revealed that 30% of the servers of these machine rooms were "comatose" (supplied by electricity but not delivering any useful service). Moreover, the computing and storage servers and the network equipment did not show electricity consumption proportional to their load. This absence was put forward by Barrosso et al. in 2007[6] and this was still the case in 2018. Many static electricity costs (independent of the work load) are still very high.
  It should be noted that energy concentration in the data centers has continued to increase. We talk today of an electricity concentration for the servers of about 1.5 kW/m^2; whereas the first data centers only consumed 200 W/m^2.[27]

Different quality metrics were proposed (notably by GreenGrid) to measure and compare the impacts of data centers. The best known, the PUE (Power Usage Effectiveness) makes it possible to understand, in a relative manner, the extra cost of energy of the infrastructures (buildings, cooling, etc.) compared to the electricity cost of the digital. Consequently, a data center that shows a PUE of 2 injects as much electrical energy into the data center's data processing than in the hosting infrastructure (cooling, lighting, problem recovery, etc.) For example, the totality of Google's data centers show an average PUE of 1.12; for each watt of electricity injected into data processing, 0.12 additional watts are needed to cool and distribute the electricity.[8]

Since the early 2000s, considerable academic and industrial research has attacked the problem of high electricity consumption of data centers by improving in parallel the cooling infrastructures (by cold air,

---

[5] Guillaume Pitron, *La guerre des métaux rares, la face cachée de la transition énergétique et numérique,* Éditions Les liens qui libèrent, 2018.
[6] Luiz André Barroso and Urs Hölzle, 2007, "The Case for Energy-Proportional Computing," *IEEE Computer*, vol. 40, Issue 12, December.
[7] Interview with Hervé Mallet, energy director at the technical and information sciences division of Orange France, April 17, 2018.

[8] Google *Data centers*: https://www.google.com/about/datacenters/efficiency/internal/

cold or warm water, natural ventilation or free cooling and the software systems composing the data centers (virtualization, scheduler, resources managers[9]).

Slow conscious-raising

Academic research on the creation of data centers and economical computing centers began in the early 2000s with the work of Wu Feng and his team at Virginia Tech (US). In the framework of the Computing in Small Space project, the researchers developed the Green Destiny Low Power Supercomputer (December 2001), which succeeded in putting super-calculators into production lowering the costs, the heat emitted, the energy consumed and the space required.

The term eco-ICT [information and communication technology] was created in France on July 12, 2009 by the General Commission of Terminology and Neology for Computer Science and Electronic Components. This commission published, in the *Journal Officiel*, the term “eco-technology of information science and communication” or eco-ICT as equivalent to Green IT (JORF 2009). According to the same source, the eco-ICTs designated the “information science and communication techniques whose conception or use permit the negative effects of human activities on the environment to be reduced.”[10] Unfortunately, this IT4Green effect, or the use of information technology making it possible to reduce the impacts of certain human activities is still very poorly evaluated and a controversial subject. Most of the studies on this subject are not sufficiently documented or serious. The scenarios evaluated show reduction impacts that are still rather negligible on the large scale.[11]

The GreenTouch initiative launched in 2010 by Alcatel-Lucent/Bell Labs focused on the reduction of electricity consumption in the communication networks. The founding members of this initiative included telecom operators – AT&T, China Mobile, Portugal Telecom, SwissCom, Telefonica; university research laboratories – Massachusetts Institute of Technology, Stanford University Wireless System Labs, Institute for a Broadband-Enables Society (IBES) of the University of Melbourne; public research organizations – CEA-LETI-Grenoble, INRIA, IMEC-Louvain; industrial research laboratories – Freescale Semiconductor, Samsung Advanced Institute of Technology, Bell Labs. The consortium next brought together about 50 industrial, academic and institutional partners. This project’s aim was to explore and rethink all the material and software components required to build a worldwide Internet whose energy consumption would be reduced by a factor of 1,000 compared to consumption in 2010 while supporting the data traffic projections and increases anticipated for 2015.

The energy efficiency of the digital in the usage phase is a full-fledged research subject in academic and industrial research. In France, the EcoInfo services group studies the impacts and rebound effects of these different phases.[12] Several tracks are being studied with focuses on the eco-design of hardware but also more recently software to improve their electricity consumption. The search for energy efficiency in these large distributed systems (data centers, Clouds, high-performance computing centers, networks) questions the way in which these infrastructures are designed[13] The coordinated and orchestrated usage of green levers (extinguishing, slowing down, optimizing, consolidating) must be studied and implemented. As a massive and internationally distributed digital infrastructure, data centers have a central role to play in order to reduce their environmental impact. They also represent key infrastructures that accompany the digital transition underway.

In international climate conferences (Conference of Parties, COP), the subject of the energy impacts of the digital arrived belatedly as a subject in itself.

---

[9] Orgerie Anne-Cécile, Dias de Assunção Marcos et Lefèvre Laurent, "A Survey on Techniques for Improving the Energy Efficiency of Large Scale Distributed Systems," *ACM Computing Surveys*, vol. 46, no. 4, 2014.
[10] http://www.cstic.fr.st/
[11] Tinetti Benoit, Duvernois Pierre-Alexis, Le Guern Yannick., Berthoud Francoise, Charbuillet Carole, Gossart Cédric, Orgerie Anne-Cécile, Lefèvre Laurent, de Jouvenel François, Desaunay Cécile, Hébel Pascale, *Potentiel de contribution du numérique à la réduction des impacts environnementaux : Etat des lieux et enjeux pour la prospective* – ADEME final report, 2016, 145 pages. ADEME is the Energy Transition National Agency in France.
[12] Groupe EcoInfo, *Impacts écologiques des Technologies de l'Information et de la Communication - Les faces cachées de l'immatérialité*, Éditions EDP Sciences, 2012.
[13] Orgerie Anne-Cécile, Dias de Assunção Marcos and Lefèvre Laurent, 2014, op. cit.

As a prelude to COP21, which was held in Paris in 2015, researchers at the Inria and members of the GDS EcoInfo warned the scientific community about the environmental impacts of the digital at the conference *Our Common Future Under Climate Change*.[14] The digital, despites its virtual aspect, is also responsible for climate change! The share of carbon emissions of this industry was, it seems, counted in the industrial sector, without any precise distinction of the dizzying growth phenomenon that it has known. Whereas the digital and the smart grids were at the heart of COP21 (of which ERDF – Enedis today – was a partner), the energy cost of the innovation and these systems was not a subject for discussion or any specific orientation. We can however note that Orange was one of the 34 French groups of the CAC 40 that made a commitment to supporting and contributing to the objectives of COP21. The company committed to reducing its CO_2 emissions per customer use by 50% by 2020 (compared to 2006) and deploying the circular economy (recycling of equipment, cellphones and others) in all its processes by 2020.
The Fondation Internet Nouvelle Génération (FING) recently proposed a white paper on the digital and the environment with a list of 26 measures notably on the sustainability of digital equipment and the generalization of eco-design.[15]

France is involved in an energy transition that aims at limiting its environmental impacts and honoring its greenhouse gas emission reduction commitments to limit global warming. However, the environmental impacts of the digital are still relatively poorly evaluated, notably in prospective terms, following the example of the *Scénario négawattt 2017-2050*, which however stresses that “the explosion of digital technologies has accelerated the already perceptible mutation toward an increasingly service-oriented approach to the energy demand.”[16] This energy transition relies on the digital, it has not however been demonstrated that the digital will help reduce environmental impacts. This is notably the result of a 2016 ADEME study.[17]

---

[14] Berthoud Francoise, Lefèvre Laurent, Gossart Cédric, “ICT is part of climate change! Can we reduce its impact and apply good practices and tools to other society domains?", "Our Common Future Under Climate Change" International Conference, Paris, 2015
[15] IDDRI, FING, WWF France, GreenIT.fr, *Livre blanc Numérique et Environnement.* http://fing.org/IMG/pdf/Livre_blanc_numerique_environnement_livreblancecolonum.pdf, 2018.
[16] Association négaWatt, *Scénario négaWatt 2017 – 2050*, 2017, https://www.negawatt.org/IMG/pdf/synthese_scenario-negawatt_2017-2050.pdf, p.8.
[17] Tinetti Benoit, Duvernois Pierre-Alexis, Le Guern Yannick., Berthoud Francoise, Charbuillet Carole, Gossart Cédric, Orgerie Anne-Cécile, Lefèvre Laurent, de Jouvenel François, Desaunay Cécile, Hébel Pascale, 2016, op. cit.

Apart from the IT field, researchers in industrial ecology and social sciences as well as historians who specialize in technology[18] have taken an interest in the environmental impact of the digital, whose effects are struggling to become a central subject in environmental public policies.

In the Île-de-France, it has been the reports by the Direction régionale et interdépartementale de l'environnement et de l'énergie (DRIEE) and the Agence Locale de l'Énergie et du Climat de Plaine Commune (ALEC) that have measured the scope and importance of this issue since 2012.

Data centers in energy planning in the Île-de-France

In the Île-de-France, the Regional climate, air and energy plan (SRCAE) adopted in December 2012, brought out that data centers have a "new potential," are a "possible source" in the framework of the development of the heat recovery energy sector. As for energy consumption, the text specifies that a "data center of 10,000 m^2 needs a power supply capacity for the connection to the electricity network of 20 MW and uses as much electricity as a city of 50,000 inhabitants."[19] The recovery of heat from data centers was perceived as a new challenge specific to the Île-de-France region but that would warrant "being better evaluated in terms of potential." The heat recovery installation of Val d'Europe in the Seine-et-Marne department (under construction at the time) is cited as an example. The regional administrations are recommended to: "contact the existing data center operators to study the possibilities of recovering and recycling waste heat (connection to a heating networking, heating buildings, swimming pools, hospitals)."[20] After the SRCAE, in 2013, the DRIEE (State administration) conducted a study on the new consumptions in Greater Paris area that anticipated, for electricity, a call for additional power of 4,000 MW broken down as follows: 400 MW for the 72 new metro stations of "Grand Paris Express", 800 MW for the additional 800,000 apartments, 1,300 MW for the 1 million jobs created in the service and industrial sectors, 500 MW for 1 million electric vehicles and 1,000 MW for the data centers.
In this 2013 study, the data centers represent one quarter of the additional electricity needs anticipated by 2030. This study had a major impact and was largely used in the press because it showed a grow compared to the SRCAE trend of over 2,200 MW, whereas a control of electricity consumption was recommended. One of the study's ambitions was to show the immense effort that was made to reach the objective of 20% renewable energy by 2020.
It was at the same period that the local energy and climate agency (ALEC) of Plaine Commune area, North of Paris, carried out a study on the data centers on its territory[21] that would be a great success in the press. Created between 2011 and 2013, this local energy and climate agency proposed (in a systemic approach to the crossing of ecological, economic and social questions) strategic and operational support on the territory and brought together public and private actors like EDF, Engie, Enedis, Icade and Bouygues. The "*Les data centers sur Plaine Commune*" study was the first conducted by the agency. It was on the eve of the 2014 municipal elections that the data center subject became a political issue in the context of opposition to the development of a data center project in La Courneuve. The agency had been called in by elected officials and inhabitants and took hold of the subject at a moment when there had been few reference studies on the subject. The document produced made it possible to understand what a data center was, its impacts and to envisage reflection elements to move toward better management of this type of infrastructure on the territory. It was notably recommended at the end of the document to work on: better transparency on the electrical power really necessary, the question of the use of local cold sources (free cooling and water cooling), heat recovery and its recycling

On the European level, the European Commission took hold of the subject and in 2008 published a Code of Conduct on Data Centers[22] intended to encourage the operators and stakeholders of data

[18] Let us notably cite Florence Rodhain Bernard Fallery, Jean-Luc-Pensel, Fabrice Flipo, Michelle Dobré, Marion Michot. cf. Flipo Fabrice, Dobré Michelle, Michot Marion, 2013, *La face cachée du numérique L'impact environnemental des nouvelles technologies,* L'échappée.
[19] "Recoverable energies, or waste energies, designate the energy quantities inevitably present or trapped in certain processes or products, which sometimes – at least partially – can be recovered and/or recycled, and which, for lack of being so, "are lost" in nature. They notably cover energy losses linked to methane production or the incineration of waste (the non-biodegradable fraction), industrial processes (in the form of heat), data centers and more generally all the processes that involve heat production." Région Île-de-France, 2012, *Schéma Régional du Climat, de l'Air et de l'Energie de l'Île-de-France,* http://www.srcae-idf.fr/IMG/pdf/SRCAE_-_Ile-de-France_version_decembre_2012_vdefinitive_avec_couverture_-_v20-12-2012_cle0b1cdf.pdf
[20] Idem, p. 204.
[21] ALEC, 2013, *Les data centers sur Plaine Commune.* http://www.alec-plaineco.org/les-data-centers/
[22] European Commission, 2008, *Code of Conduct on Data Centres Energy Efficiency*.

centers to implement good practices to reduce their environmental and economic impact, and on the security of the energy supply. The application of efficient energy consumption techniques of the servers, the virtualization of services on the large scale and better management of the servers helped limit the increase in this consumption. However, a great deal of waste was still present on every level.

1.2 Environmental blind spots and risks

Pollution and risks

As early as 2013, the ALEC Plaine Commune identified three risks and pollution connected to large data centers:

- The presence of a large quantity of fuel on the sites;
- The noise caused by cooling installations, even by the operation of data centers;
- Electromagnetic pollution.

Diesel oil storage
All the data centers are equipped with fuel tanks to produce energy in the event of an electricity cutoff. There is therefore a risk for the environment and people in the event of a leak, even an explosion of these tanks. Moreover, the use of backup generators can be an air pollution factor during tests and emergencies. This equipment is moreover subject to ICPE regulations (installation ranked for the protection of the environment) and periodic controls in France. To give some idea of an order of magnitude, the Atos data center in Saint-Ouen (93) stores 60,000 liters of diesel oil to provide the generators on the site with a power supply for 48 hours. The question of depolluting sites, after use, will also be raised in the future, in the same way as dismantling gas stations today.

Sound pollution
Another point has raised strong protests when certain data centers are installed: the noise of cooling units. Like any ICPE, data centers must respect noise regulations (decision of January 23, 1997). This regulation limits the sound emission of installations depending on their activity and the time of day. It is therefore necessary to do an impact study on noise before building a data center.

- It was on this point that the inhabitants of La Courneuve attacked Interxion (a European colocation data center operator) during its installation on the rue Rateau. This complaint, spread by the media, even went as far as the decision to cancel the operating authorization of the data center in October 2015.

- A similar problem occurred on a data center by the operator Zayo, in the Sentier district in Paris in 2016. Zayo was forced to undertake work to solve this problem.

Electromagnetic fields
Another problem related to data centers is the risk of disturbances linked to electromagnetic fields (the question of the harmfulness of these electromagnetic fields is obviously not limited to data centers). At this time, the official scientific consensus is that these electromagnetic waves do not present any proven health danger:

- In October 2013, the Anses (National agency for health safety for food, the environment and the workplace) published a collective technical report (submission no. "2011-SA-0150"). Backed by 308 scientific articles, the report concluded that for the majority of the effects, the level of proof was insufficient. Only the level of proof concerning gliomas (tumors) was pointed out as "insufficient in the general population, limited for intensive users."
- In 2009, the National Academy of Medicine published a communiqué titled "Reducing the exposure to waves emitted by cell towers is not scientifically justified." However, in 2011, the WHO classified the electromagnetic waves emitted by connected mobile terminals as "potentially carcinogenic." The existence of this human health risk was formally included in law no. 2015-136 of February 9, 2015 whose aim is to limit the exposure to waves of the most vulnerable people. Associations such as Robins des toits moreover defend the fact that a risk to these waves exists and put forward the principle of precaution.

Impacts on air, water and soil

The specific environmental impact of the data center does not seem to have been studied to any degree at this stage concerning:

- The island effect of urban heat;
- Water consumption;
- Biodiversity.

We can ask ourselves if data centers have a specific impact on these areas, different from that of a logistics platform or an industrial building, for example.

The island effect of urban heat

During our discussions with IDEX in March 2018, its director of heating and cooling network development, Guillaume Planchot, stressed, talking about the Global Switch data center: "In Clichy, all the heat from the condensers is discharged into the atmosphere. It contributes to the urban heat island phenomenon that consists in increasing the temperature locally felt near these cooling towers."

Heat recovery is therefore not only a question of waste energy recovery, but also the fight against the urban heat island phenomenon. Let us recall that the Seine-Saint-Denis department experienced an excess mortality of 160% caused by the heatwave in 2003, which made in the second most affected department in France.[23] It is a territory that has accumulated vulnerable populations and a very mineral urban fabric.[24] The many data centers installed in the southern part of this department therefore potentially aggravate this situation.

We may note that in Aubervilliers, the Equinix data center (rue Waldeck Rochet) uses a light coating on part of its roof to favor solar reflection, in this way limiting local warming.[25] This good practice, common to many buildings with a flat roof, is sometimes made difficult for data centers, whose roof is often filled with technical equipment that is not very visible from the ground, but very rarely covered by a real roof. A few data centers moreover are developing planted roofs, also having a positive impact on the temperature and humidity of the air around them, for example the operator Neocenter Ouest in Nantes.

The impact on water

Water consumption by data centers (to cool them) is an issue that is hardly present in France, but much more so in places like California, subject to chronic episodes of drought. A data center of 15 MW can use up to 1.6 million liters of water a day (or 1,600 m^3) according to the vice president for operations of Infomart, Paul Vaccaro, an American data center operator.[26]

If very few installations have closed water loops that minimize consumption, most of them are connected to local drinking water networks, which represents a major treatment cost for local communities, but can also force them to resize their equipment. This was case for the city of Prineville (Oregon) when Facebook and Apple data centers arrived. However, these two companies co-invested with the city for a new wastewater treatment center.

A very small number of data centers have turned to alternative solutions. This is the case of the data center Infomart in San Jose (California), and that of Google in Douglas (Georgia, United States) that use local graywater for cooling. This implies investments that these actors considered relevant for reducing their water bill. The local administrations accompanied them, also deriving an environmental and economic benefit from them.

This type of project remains not very widespread, but cities like Paris that have a non-drinkable water system can offer a very interesting option for data centers in the same way as their own drinkable water network, consequently economized.

The impact on biodiversity

The configuration of large data centers in particular, creating enormous closed footprints, heavily fenced-in, is not favorable to ecological continuities. Nonetheless, depending on the communities and their PLU/PLUi (local urbanism plan/local intercommunal urbanism plan), there are obligations concerning unbuilt outdoor spaces as well as different land use coefficients that can minimize the sealing of the ground and favor biodiversity.

---

[23] Institut de Veille Sanitaire, *Impact sanitaire de la vague de chaleur d'août 2003 en France. Bilan et perspectives,* October 2003.

[24] DGE-CDC-CGET, 2015 *Guide sur le Cloud computing et les datacenters à l'attention des collectivités locales*. https://www.entreprises.gouv.fr/files/files/directions_services/secteurs-professionnels/numerique/guide-cloud-computing-et-datacenters-2015.pdf

[25] Site visit in March 2018.

[26] Interview in September 2017.

ICPE studies have a fauna, flora and natural milieu section, notably including impacts on environmental perimeters such as the Natura 2000 zones and the ZNIEFFs (natural zone of ecological interest, fauna and flora). They are however more positioned as a tool to minimize negative impacts than to improve the existing situation.
A point to be noted in terms of land use, and raised on several occasions by data center operators, concerns the regulations on parking. As they only generate a low number of jobs, standards can often be lowered for the number of parking places to be guaranteed, potentially freeing up more unbuilt outdoor space and planted surfaces.

1.3 The frenetic growth of data storage and their processing

Despite progress, the current trends in digital practices, the constant growth of the Cloud, the development of the edge and the Internet of Things (IoT), the tendency toward the centralization of data by Big Tech (Google, Amazon, Facebook, Alibaba…) are factors that increase the number, power and energy consumption of data centers.

According to Cisco, Internet traffic (IP) will have grown threefold between 2016 and 2021.[27] This growth is fed by several phenomena described here and is accompanied by ever-increasing storage and processing spaces.

The Cloud and the outsourcing of data storage

Since the early 2010s, the continuation of the digitizing of the economic has pushed many companies to outsource some of their IT services, to give up storing their data in their own building, to turn it over to Cloud specialists whose dominant actors are Microsoft Azure, Amazon Web Services, Google Cloud, Salesforce as well as OVH in France. The Cloud makes it possible to host one's data, applications and computing in an external data center and to have access to them everywhere via the Internet. The infrastructure and services are managed by a service provider that handles operation, maintenance and support. There are three families of Cloud services:

- IaaS (*Infrastructure as a Service*) that corresponds to the rental of computing and storage capacities;
- PaaS (*Platform as a Service*) that makes available to clients ready-to-use development platforms to develop and roll out their own applications;
- SaaS (*Software as a Service*), that is a complete offering of business applications and software that the clients pay for on a use time basis or per number of users.

A Cloud can be "public," that is, shared among an unlimited number of clients; it can be dedicated to a specific client, calibrated according to its needs, and therefore "private." Lastly, the Cloud can be "hybrid." It then combines the use of a public Cloud (notably in a period of load increases) in a private Cloud environment.[28].

Individuals preceded in the same way with their personal data, sometimes with little choice: music storage via services like Spotify or Deezer, photos via Google or I-Cloud (Apple), file exchanges via Dropbox, hosting of e-mails and attached files via Gmail (Google), Yahoo or Microsoft, contents and exchanges with Facebook. Consequently, computer terminals have increasingly less storage memory, flexibility (and generativity) and smartphones are gradually taking over for computers for Internet access. The Baromètre du Numérique France 2017 indicated that 73% of French people now had a smartphone

[27] Cisco, *Visual Networking Index: Forecast and Methodology, 2016 - 2021*, 2017,op. cit.
[28] For more information, see *Guide sur le Cloud computing et les datacenters à l'attention des collectivités locales*, July 2015, DGE-CDC-CGET.

(+8 points in one year) whereas only 17% of French people had one in 2011. The fixed-line phone (-1 point) and the computer (1 point) lost ground, the connection rate to the Internet remained stable (85%).

The worldwide Cloud has been developing since the second half of the 2000s (Amazon Web Services was created in 2006, for example), but even more as of 2010, the date starting at which the Cloud caused the accelerated development of data centers. According to Cisco,[29] all the operations connected to the Cloud represented, in 2017, 90% of the data centers' traffic (and will represent 95% in 2021). In France, the IDC firm stresses that the private Cloud market increased by 20% between 2016 and 2017, and 25% for the public Cloud (in revenue).
The Cloud operators, notably the dominant trio (AWS, Google, Microsoft) have developed their own data centers, called hyperscale, because their sizes are enormous, but also use colocation data centers where many other clients (in Equinix, Interxion, DATA4 or Telehouse) are hosted. The use of the data centers just mentioned is explained by their location, often much more metropolitan, near consumer markets and companies, but also because the growth in the demand for Clouds has exceeded these operators' new construction capacities, despite the nevertheless frenetic rhythm of new constructions. Colocation data centers therefore remain gates to the network and comprise strategic Internet exchange points.
It must be pointed out that the migration movement of companies to the Cloud is continuing, and the suppliers are rolling out aggressive marketing campaigns to accelerate this transition. Consequently, in the world as in France, the different types of Clouds will continue to take on major importance in the economy. According to the same Cisco report, global Internet traffic connected to the Cloud will be multiplied by 3.3 between 2017 and 2021. Data centers will then have a storage capacity four time higher than in 2017, or 663 exabytes.

Nevertheless, not every company will migrate to a Cloud, or at least not totally, and this for several reasons:

- Desire to control its infrastructure (depending on its activity, history, in-house expertise…);
- Size of the company and sensitivity of the data sufficient to justify having its own data center(s).

Certain companies locally host their data, and there are a large number of corporate data centers, in particular but not exclusively in the banking sector: EDF and Orange in Val-de-Reuil, BNP Paribas and Natixis in Marne-la-Vallée to offer French examples. This above all concerns the companies of the CAC 40.
The state and local administrations have and can have their own data centers, notably for archiving but not exclusively. The question of the sovereignty of the data has a strong impact on their choices and obligations (see below). We can cite the Osny data center in the Val-d'Oise area (800 m^2), built for the customs department and used by several ministries.

The growth of exchanges and data processing, the explosion of connected objects

In addition to the migration of existing data and in-house corporate infrastructures to data centers, the creation of new data, in ever better definition therefore taking up more room and energy, continues to explode and this trend will continue in the next few years. Several phenomena explain this growth:

- The digitizing of the economy continues to affect companies that still hadn't started this process.
- By 2020, according to Gartner, the Internet of Things (IoT) will reach 25 to 30 billion connected pieces of equipment (50 to 125 billion is mentioned for 2030), without counting tablets and laptops: this equipment encompasses smartphones as well as connected watches and home automation devices. According to Intel, the so-called autonomous vehicle is itself a connected object that will product 4 terabytes of data per day to process and store. Between the self-fulfilling prophecy and real growth, this escalation raises questions in a world where the limits of growth have been largely exceeded.

[29] Cisco, 2017, *Global Cloud Index: Forecast and Methodology, 2016 – 2021,* op. cit.

- The smart city has become a dominant paradigm of contemporary urban planning, which implies the collection and processing of new data via multiple sensors, as well as the creation of digital doubles of buildings, cities and territories in the form of the BIM (Building Information Model), the CIM (City Information Model) and numerous 3D platforms.
- Individuals are also taking part in the explosion of data exchanges via the ever-increasing growth in exchanges of videos, photos, messages, likes, comments, notably carried by the social networks. This exponential production of personal data is largely favored by these same social networks, it is at the heart of today's Web economy, based on advertising, therefore on the profiling of Internet users and the collection of their personal data. A data economy has consequently developed around data brokers like Datalogix and Acxiom, whose activity is the exploitation of personal data. Acxiom, an American company, has, according to the Federal Trade Commission, nearly 700 million data on consumers throughout the world, enabling it to generate revenue of nearly 850 million euros in 2016.[30]
- Video on demand (or streaming) is accelerating as fast as needs: it represented 63% of global Internet traffic in 2015 and should reach 80% in 2020.[31]

The figures succeed each other, and are just as dizzying on energy consumption. They should be considered with a great deal of caution. They cover a range of potentially very different scenarios and hypotheses and have very varied orders of magnitude.

In 2013, the researchers of the GreenTouch project[32] estimated that the electricity consumption of the IT world was about a hundred gigawatts of instantaneous power constantly supplied on the worldwide scale (117.6 GW or the power of over a hundred nuclear reactors). The three large families of consumers (terminal equipment, network equipment and data centers) had rather close consumptions.
Worse yet, a 2015 study by Anders Andrae and Tomas Edler of the Huawei R&D center, estimated that the IT sector (networks, devices, data centers, from equipment production to use phases) consumed 7% of electricity worldwide in 2013,[33] or the power of 210 nuclear reactors during one year. Data centers themselves represented 2% of the worldwide figure, or 420 TWh or 60 nuclear units. The projections reach a maximum of 13% of the world's electricity consumed by data centers in 2030, and 51% for the IT sector in its totality, or respectively 1,130 and 4,400 nuclear reactors. This enormity is quantified.

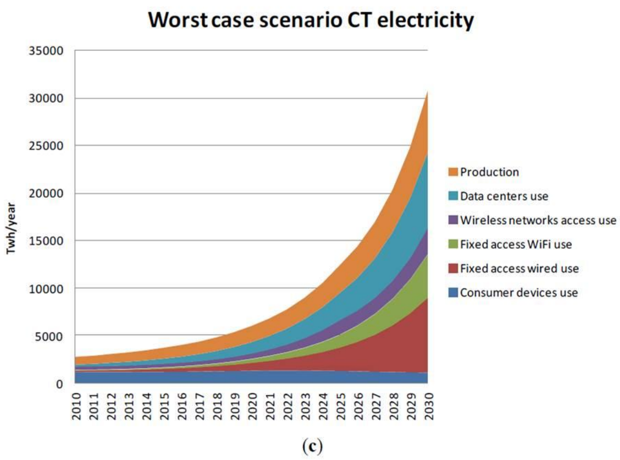


Figure 9. (**a**) Trends per CT category for best-case global electricity usage 2010–2030. (**b**) Trends per CT category for expected-case global electricity usage 2010–2030. (**c**) Trends per CT category for worst-case global electricity usage 2010–2030.

Figure 2. Electricity consumption trends 2010-2030: worst-case scenario. Credits=©Study Andrae/Edler

[30] For more information: https://atelier.bnpparibas/smart-city/article/data-brokers-commerce-donnees-personnelles
[31] Cisco, *Visual Networking Index: Forecast and Methodology, 2016–2021,* 2017, op. cit.
[32] GreenTouch project: GWATT: http://alu-greentouch-dev.appspot.com
[33] Andrae Anders S. G. and Edler Tomas, 2015, "On Global Electricity Usage of Communication Technology: Trends to 2030," *Challenges* 6, 2015, pp. 117-157. In this study, electricity consumption in 2013 was estimated at 21,000 TWh (7% represents 1,470 TWh) and the projections for 2030 reach 61,000 TWh. A nuclear reactor has an annual production of 7 TWh.

The emergence and development of the edge

The computing edge is defined as a distributed (or decentralized) IT architecture in which the client data are processed on the periphery of the network, as close as possible to the source generating the data. These techniques can be combined with the technologies of the Content Delivery Network (CDN) type, as, for example, all of the data centers of the Akamai company divided among many countries in order to deliver rapid and personalized ad contents on the Web. The edge also makes it possible to respond to the future challenges of the mobile networks (type 5G, with latency needs of 10 ms) that are based on a rapid response from Cloud services in order to support new services for smartphones and mobile equipment.
It is therefore also an IT designed to accompany the development of connected objects. These objects can process or store the data that they don't need to be sent to a central hub, consequently lightening the Internet network, and improving the speed of local exchanges. This local work can also be carried out by micro-data centers. The IDC firm estimates that 40% of the data of the IoT will be processed, stored, analyzed and executed on the edge by 2020.[34]

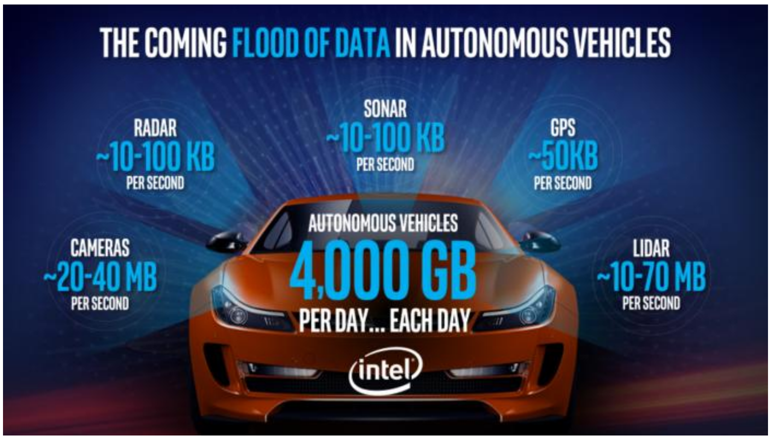


Figure 3. The data of the so-called autonomous vehicle, 2017. Credits=© Intel.Corp.

Intel projects that each connected so-called autonomous car will produce 4 terabytes of data per day, which is the equivalent of the quantity of data produced in one day by 30,000 people, the company points out. Even if most of the data is processed by the car's internal computing equipment, a great deal of data will have to be treated by external data centers (in edge mode or centralized).

Concepts are consequently being developed, to imagine what the micro-data center of tomorrow will be: some of the servers in metropolitan data centers? Cabinet-data centers in a dense milieu or immersed in the oceans like Microsoft's data centers (Natick Project)? A micro-installation in service or residential buildings (following the example of digital boilers proposed by the French company Stimergy or electric heating from the French company Qarnot Computing)? Mini-data center containers like the StarDC Marilyn of the Céleste company or the more low-tech one proposed by the Electrical and Computer Engineering Department of Rutgers University in New Jersey. This micro-data center called Parasol[35] is installed in a container on the roof of one of the university's buildings. The IT part is based on two processor bays and low-consumption architectures and is partially powered by solar panels. It uses free cooling. Automatic switching systems favor maximum use of renewable energy. The Parasol system is a micro-data center demonstrator (edge computing type) with low energy consumption; it serves as validation for researchers working on data centers with high energy efficiency.

This reorganization of virtualized architecture of data center federations implies a dissemination of smaller data centers. How can the same quality of service, resistance to breakdowns, security on these

[34] MacGillivray Carrie and Turner Vernon, "IDC FutureScape: Worldwide Internet of Things 2018 Predictions," Web Conference: Tech Buyer, 2017, https://www.idc.com/getdoc.jsp?containerId=AP43372517
[35] Parasol micro-data center of Rutgers University, New Jersey, US: https://www.cs.rutgers.edu/content/parasol-rutgerss-green-udatacenter

new widely distributed infrastructures be guaranteed? Risks of oversizing digital infrastructures are to be feared. The edge model is not yet stabilized as can be seen in the famous innovation curve of the Gartner firm, since it is in the innovation trigger phase and considered mature two to five years from now.

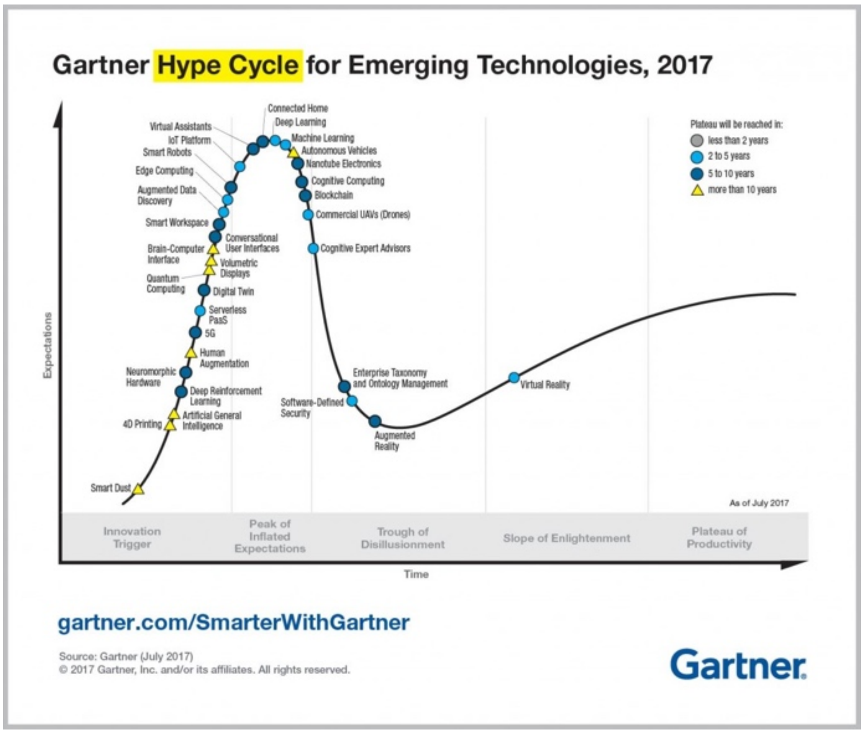


Figure 4. Emerging technologies curve, 2017. Credits=© Gartner.

Talking about the pervasive or ubiquitous digital takes on even more corporeality in space with the edge, since all the objects and infrastructures that follow will have their role to play in data storage and processing:

- At home: video game console, internal box, household appliances, personal laptops, home automation personal assistants;
- Mobile objects: smartphones, 5G antennas, connected watches;
- Service buildings, public facilities, stores: edge servers, micro-data centers, local Wi-Fi, sensors;
- Mobility: connected traffic lights, connected vehicles.

As a result, alongside the trend of massifying data centers with the hyperscale data centers of GAFAM, the return to the local scale is also a strong trend, that a priori complements the digital system rather than competing with it.

Big Tech as an additional factor in data creation, centralization and storage

The hyperscale data center phenomenon – which France has been spared for the moment – is the most spectacular illustration of the economic concentration of the digital actors that can now be called Big Tech (by analogy with Big Oil, Big Tobacco, Big Pharma). Their monopoly on collecting personal data induces very large-scale data centers, but also a spatial concentration of data that, despite redundancy, is situated opposite the pre-Web model of the Internet, when storage was carried out more on a peer-to-peer basis, and when the distributed nature was synonymous with resilience.

Cisco[36] considers that hyperscale data centers are those that are operated by equally hyperscale Cloud operators. The company identified 24 operators of this type in 2017, which must fulfill the following criteria:

- Over $1 billion annually in revenue from IaaS, PaaS or hosting services (like Amazon/ AWS, Rackspace, Google);
- Over $2 billion annually in revenue from SaaS services (Salesforce, ADP, Google);
- Over $ billion annually in revenue from the Internet, search engines and social networks (Facebook, Apple, Yahoo);
- Over $8 billion annually in revenue from e-commerce and online payments (Amazon, Alibaba, eBay).

According to this report, these hyperscale data centers will rise from a number of 338 in late 2016 to 628 worldwide in 2021, representing 53% in this year of all the servers installed. Web traffic on these sites will increase fourfold, going from 39% of the total traffic between all the data centers to 55%.

Their growth will therefore continue at a very fast pace and everywhere in the world.

Digital sovereignty and the protection of personal data

Lastly, two regulatory factors impact the data center market:

- The protection of personal data;
- Digital sovereignty.

The General Data Protection Regulation (GDPR)[37] is a European regulation that became enforceable on May 25, 2018, and that harmonizes the legal framework on the EU scale. It improves the protection of personal data by requiring clear consent from Internet users on the processing of their data, permitting a certain “right to be forgotten”, data portability, by strengthening physical and IT security, mandatorily warning users of theft of their data or an intrusion. All the actors handling personal data, including data centers, must comply with the GDPR. In the event of non-respect, a fine can be levied as high as 4% of annual revenue and €20 million maximum will be demanded. As this regulation is European, it will not however contribute to widening the gaps between data center host countries.

Moreover, an information note from the French Central Department of Local Administrations (DGCL) relative to Cloud computing (April 2016) requires that French local administrations host their data in France by an operator that guarantees that all the data are stored and treated on French territory, in a sovereign Cloud. As the data from public administrations are considered archives, they fall under the national treasures system from their creation and it is therefore illegal to keep them outside French soil. Two sovereign Clouds were consequently created for this purpose in 2012 with the government as shareholder through the Caisse des Dépôts et Consignations (CDC), and in partnership with SFR, Orange, Thalès and Bull: Cloudwatt and Numergy. In the end, they did not convince potential clients. In 2015, government state withdrew from it and Orange took over Cloudwatt as a subsidiary of its Cloud, SFR did the same with Numergy. In the meantime, French Cloud actors developed, like OVH, Outscale and Ikoula, and the international operators succeeded in establishing hosting guarantees in France, through local subsidiaries, even if this did not fulfill all the sovereignty conditions since the subsidiary belongs to a foreign holding company. The circular of 2016 does not include sanctions, its effect was therefore not as impactful as it would have been if a massive 100% French data center development had taken place. In April 2019, the French economy minister evoked the necessity of a sovereign cloud again.

[36] Cisco, *Global Cloud Index: Forecast and Methodology, 2016–2021*, 2017.
[37] By personal data, the GDPR means any information likely to directly or indirectly identify a person.

2. Digital territories: concentration and dispersion

In an article in 2003, the geographer Bruno Moriset pointed out that "the real estate infrastructures of the digital economy continue to follow traditional siting plans, with a preference for central peripheral districts undergoing renovation."[38]

Since 2003, several phenomena have modified this geography:

- When the article was written in 2003, the economy was just barely recovering from the bursting of the dot.com bubble, and since that time, we have seen the explosion of the digital economy and the emergence of very powerful actors in the sector;
- The Cloud has been very strongly developing since the 2010s;
- Especially, data centers have been covering a wide range of services and activities, which has induced different siting and development strategies;
- Lastly, natural risks are not a discouraging criterion in the very booming markets such as, for example, Silicon Valley.

This complexification has also caused the constitution of territories with contrasting digital dimensions:

- Ultra-metropolitan concentrations very close to Internet Exchange Points;
- Peri-urban areas or digital activity zones;
- Rural spaces faced with the large scale of the digital.

It must be noted here that if hyperscale data centers are fascinating architectural objects, the hundreds of thousands of square meters they represent in Oregon, for example (probably between 400 and 500,000 m^2) are to be compared to the 400,000 m^2 (2016) of data centers of all kinds present in the San Francisco Bay area.[39] It is therefore important to examine their entire diversity to better understand their impacts.

2.1 Siting, scale and typology strategies

Location criteria that vary according to uses

Two location criteria are genuinely structuring:

- Being located near the optical fiber Internet network, notably the principal axes that are the "Internet backbones," to be connected to the Internet Exchange Points, platforms where all the networks that disseminate information in the world are connected;
- Having enough electrical power for its installation and possible development, in a stable and reliable way, and preferably inexpensively. This can be paired with a source substation. An imponderable criterion at this point, this could change in the future.[40]

These criteria are weighed against each other, depending on the type of data center operator:

- For example, the real estate can be expensive, if being in a dense metropolitan zone, as close to the users as possible, is crucial. Consequently, the data centers of Silicon Valley like those of Equinix and Vantage, for example, are developing on very high-priced land, because the

[38] Moriset Bruno, "Les forteresses de l'économie numérique. Des immeubles intelligents aux hôtels de télécommunications," *Géocarrefour*, vol. 78/4 | 2003, put on line on August 21, 2007.
[39] Lasalle Jones Lang, 2016, *Data Center Outlook. Strong Demand, Smart Growth*, report by JLL Americas Research.
[40] Microsoft's unexpected experience in Clondalkin, near Dublin, shows that Big Tech can also handle their own energy production. Faced with the incapacity of the transmission network to incorporate the enormous increase in load of the hyperscale data centers, the company has been building for the last three years its own installation equipped with 16 gas-fired generators for a total power of 18 MW.

proximity to the world of IT and very connected users is profitable enough to warrant the expense. Land prices are high but the return on investment justifies them. In the same way, ZAYO has a data center in Vélizy, as well as in the center of Paris (Les Jeuneurs site). The sites are complementary, the one in Paris is more restricted but the prices there are three times higher than those of Vélizy.[41] Proximity to the user pays.

- Another example: a very large data center can be installed in rural territories, as Amazon (AWS) in Umatilla (Oregon), along the Columbia River, or Facebook and Apple in the heart of Oregon (Prineville) have done, if there is access to an optical fiber private network to very quickly connect to the Internet Exchange Points. There is an enormous amount of affordable land, but far from users; optical fiber, however, enables very rapid connections. The large data centers operate in a complementary way with those in metropolitan zones and take over once the connection is established with the Internet users.

However, we can observe that the hyperscale data center actors, like Microsoft, AWS, Google and Facebook, have such considerable technical and financial resources that they can more easily weigh all these factors than colocation actors, data centers of proximity (called regional data centers), large companies or universities.

A certain number of complementary siting criteria must be mentioned:
- Security;
- Absence of habitations nearby;
- Reactivity of the host locality in administrative steps;
- Availability of renewable energies and specific rates for data centers;
- Various tax incentives;
- Abundant and affordable land, with the fewest constraints and servitudes possible.

We will see later on that these criteria are also evaluated according to the specificities of the data centers: size, needs, services, clientele, activities.

Scales and typologies

There are a great many ways to classify data centers.
- By type of operator: (hyperscale, colocation, regional, corporate…); which differentiates data centers from infrastructure (hosting outsourced by the clients) and operation (built by and for a company);
- By the operator's degree of Internet connectivity: on a backbone or a local loop;
- By size of the building: hyperscale*,* intermediate, small*…*;
- By level of information security: via classification by level called Tier and managed by the Uptime Institute: Tier 1 being the least redundant (availability of 99.67% or 28 hours of annual accumulated shutdown, Tier 4 the most reliable (99.9%).

It must be noted that according to the study by ENR'CERT of 2016,[42] conducted by professionals in the sector, infrastructure (or colocation) data centers represented 15 to 20% of the total energy consumption of data centers and operation data centers (corporate) 80 to 85% in France.

[41] Interview with Frederick Coeille, president of Zayo France.
[42] ENR'CERT, *L'efficacité énergétique dans les data centers. Etude gisement du parc français,* ENR'CERT study conducted with the ATEE, the ADEME, the CRIP, the GIT, the GIMELEC and the CESIT (today France Data Centers), 2016. http://www.orace.fr/lefficacite-energetique-data-centers-etude-de-gisement-parc-francais/

Sizes of data centers, crossed with uses and according to type of operator.

Uses/size	small	intermediate	large	hyperscale
Edge	X (EdgeConnex, Orange)		X (Equinix)	
Cloud			X (in colocation actors)	X (Big Tech)
Colocation			X (Interxion, Digital Realty)	X (QTS, OVH)
Regional hosting		X (Céleste)		
Operation (companies, the government)	X (cabinets)	X	X (EDF, BNP)	X (SFR, Orange)

For André Rouyer of the GIMELEC (Groupement des industries de l'équipement électrique, du contrôle-commande et des services associés), in France, 30% of data centers are of the colocation type out of the total number of data centers. He moreover foresees the development of intermediate or local data centers "for latency, proximity, confidentiality and political reasons."[43]

It is important to talk about the size of data centers because it is often asserted that it is the small data centers, numerous and not very efficacious, that reduce the global energy efficiency of the sector, while energy performance would increase with size (economy of scale and standardization) and if the building is new. In fact, hyperscale data centers are new buildings with more rigorous environmental standards. Small data centers that are server rooms or cabinets dispersed in companies are extremely difficult to identify in France and generally consume more energy.
A study was done by the Lawrence Berkeley Lab on this subject[44] for the United States, furthermore proposing an interesting classification of sizes:

- The data centers with an area between 1 and 100 m^2 (the cabinets are under 10 m^2);
- The intermediate data centers between 100 and 2,000 m^2 (the regionals between 100 and 200 m^2);
- The large data centers whose area is greater than 2,000 m^2.

Séverine Hanauer, an expert at the data center company Vertiv, asserted in December 2017[45] that there are worldwide:

- 2.8 millions sites of fewer than 500 m,^{2} considered rooms and cabinets;
- 85,000 sites considered intermediate of more than 500 m^2 with between 50 and 100 servers per site;
- 8,000 sites of large data centers more than 500 m^2 comprising between 1,000 and 1 million servers per site.

Finally, for France, the ENR'CERT cited above chose the following ranges:

- Small data center: between 1 and 500 m^2;
- Intermediate data center: between 500 and 2,000 m^2;
- Large data center: between 2,000 and 5,000 m^2;
- Hyperscale: over 10,000 m^2.

None of these categories really takes into account the object data centers that are:

- The Q-Rad by Qarnot Computing: radiator performing distributed computer calculations, with its German equivalent Cloud and Heat;
- The digital boiler by Stimergy, or the one by Asperitas.

[43] Interview with André Rouyer, head of the infrastructure and digital committee at Gimélec, March 23, 2017.
[44] Mohan Ganeshalingam, Arman Shehabi, Louis-Benoit Desroches, *Shining a Light on Small Data Centers in the U.S.,* Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Laboratory, June 2017.
[45] During the encounter "Les data centers dans la société de demain," organized by Global Security Mag, December 5, 2017.

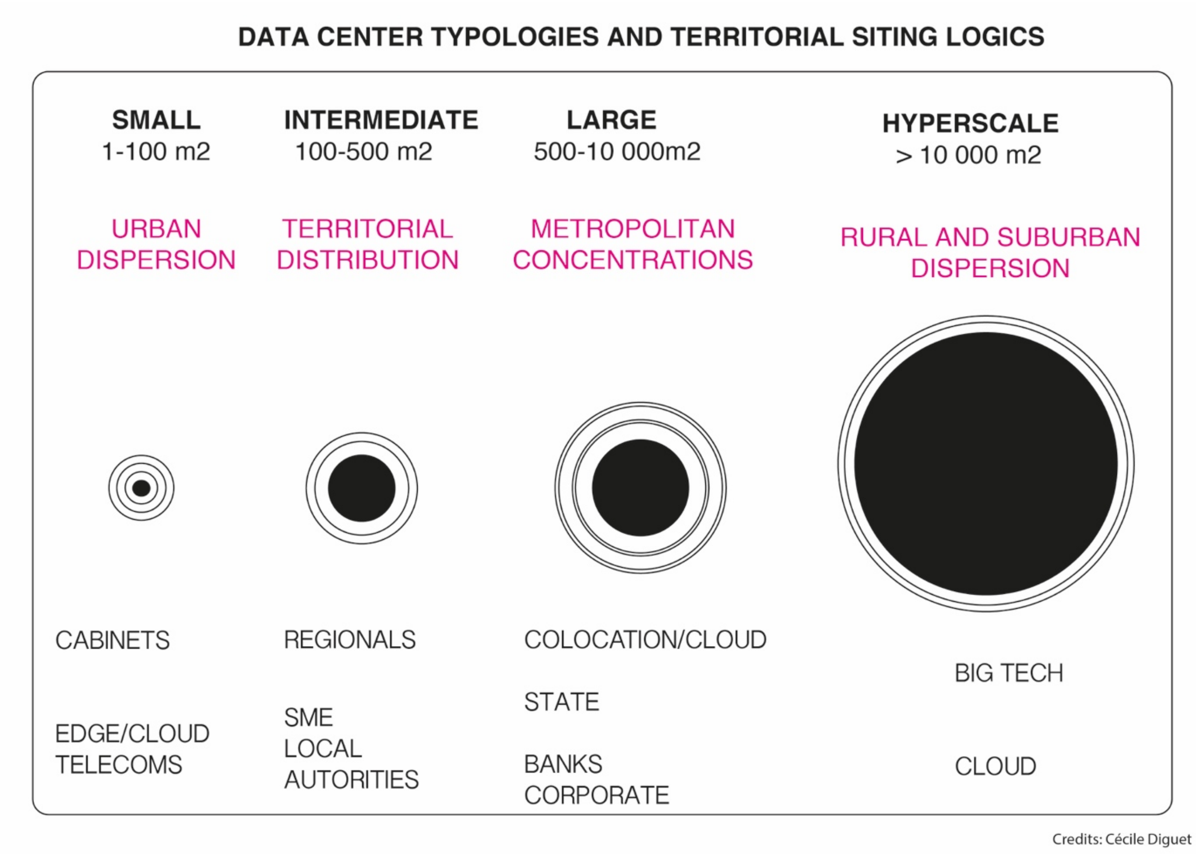


Figure 5. Diagram of increasing scales, uses and spatial siting modes of data centers. Credits=©Cécile Diguet.

Each type of data center has a different spatial siting mode, which will impact the territories according to particular modalities:

- Small data centers are distributed in urban territories and this trend will increase with the development of the edge and the Internet of Things;
- Regional data centers for the SME, local administrations, universities more follow a siting model like the national urban networks of large and mid-size cities;
- Colocation data centers are especially sited in large metropolises;
- Hyperscale data centers prefer being sited in not very dense territories like the rural or peri-urban where land is abundant and not very costly.

2.2 Architectural forms

An infrastructure without architecture

The absence of architecture dedicated to digital infrastructures and more specifically data centers could be explained by three reasons.
The first is historic, since the data center was not initially thought of as an autonomous program, but as an outgrowth of the network. In fact, data centers are the almost organic extension of server cabinets and IT rooms originally incorporated into office buildings, university or research complexes. The change in scale occurred gradually: a much larger cabinet, then a dedicated IT room. The initially decentralized nature of the Internet moreover favored a multiplicity of actors, and uncoordinated developments without any global vision that could have contributed more in-depth architectural thinking.

The second is due to the speed of the Internet's development, when the commercial Web was created in the early 1990s, which favored a certain opportunism in the siting choices of server rooms and meet-me-rooms. Data centers rushed to be near Internet Exchange Points, strategic crossroads of the Web and the Internet. Everything was very quickly concentrated to rapidly win market shares. We then observed a great heterogeneity not only of the sites chosen but also of the equipment used (which would be gradually standardized). Many data centers were installed in historic buildings of the telecoms as in the former telecom companies in New York, at 60 Hudson Street, the former corporate headquarter of Western Union, and 32 Avenue of Americas, the former corporate headquarters of AT&T. In Paris, the France Telecom company then Orange kept the emblematic historic sites at the heart of the capital like the Beaujon or Montsouris data center in a former bunker, but the trend was toward consolidation, regrouping and standardization. It was in this perspective that Orange had built, in Val-de-Reuil, an enormous data center and plans to build one or two others by 2030.
The first data centers were also installed in buildings already used by the electronics industry in a cluster effect as in Hillsboro near Portland (Oregon), in Silicon Valley in Santa Clara, or on former industrial sites like in Plaine Commune in the Île-de-France.

The third reason is that the major companies in the colocation sector like Digital Realty, CoreSite and Equinix are above all real-estate investment funds.[46] In the 2000s and even more in the 2010s, a period of constructing new data centers in dedicated buildings opened, but the investors' priority was a rapid return on investment of the facility. Creating architecture for a data center or installing a heating network is a constraint and an additional expense, only justifiable if the administration where the infrastructure is sited has made an urgent request. Colocation data centers (which therefore exclude those of companies or Clouds like Google or Microsoft) have become real estate products with high yields. Therefore there is almost never any architecture. This does not prevent thinking of the product as something mass-produced and of its interior design. These buildings are subsequently deployed on the "shoebox" mode, their envelope not suggesting the strategic importance of their content, thus contributing to their discretion and the creation of an invisible digital technical system. On a larger scale, it is the typology of the warehouse or the factory, to which Google's first data center at The Dalles (Oregon) or those of Amazon Web Services, not far from Umatilla and Port Morrow, can be compared. Certain data centers however make an effort to integrate the facility into the surrounding architecture and landscape, for example those of Facebook and Apple in Prineville, Adobe in Hillsboro designed by the American Gensler agency, or, for colocation, the Core Site data center in Santa Clara.

Organizing and creating architecture for data storage: a recent history

If we can note a lack of architecture for the data center program, there is nonetheless a concern about architectural and urban integration, notably by:

- The local authorities who wish to hide the data center on the roof, camouflage the backup generators, make them look like offices rather than an industrial building;
- The data center operators that are concerned about the well-being of their clients: giving quality to the spaces in which their technicians work better to sell them their spaces and products through the quality of the premises (marketing dimension).

The buildings constructed to host data centers present several technical particularities:

- Extreme sturdiness of the structures and floors, to support the floor load (weight of the servers and technical installations): between 500 kg and 1T/m²;
- Adaptability for installing the cables;
- High ceilings (often 4 or more meters);
- Flexibility of the interior and open spaces, a minimum of posts.

Data centers present a few major characteristics in terms of form, volume, density and program:

- For new construction, the image of the box persists. They are often single-story rectangular buildings in the zones where there is no land shortage, if not, three or four-story buildings. Great height is rare except in certain American or Asian cities.

[46] REIT, real-estate investment trust, that enables their activities to benefit from considerable tax optimization.

- For old construction, the data centers can be housed in an existing building, provided that it offers very large spaces, even infrastructures: a military site, a port authority (former logistics sites), former factory, often already containing diesel oil tanks, water tanks, etc.
- The imaginary dimension of the bunker (the IT bunkers) persists. The data center is an ultra-secure surveillance architecture, even if the campus typology makes it possible to put part of the control systems outside the building. We can however note an increase in the closed black box with a more controlled opening vis-à-vis the exterior (windows on the façade, work on the surrounding area) as well as the interior (transparent partitions to see the inside of the data center from the hallways as in the Equinix V5 building in San Jose).
- The space is usually partitioned into two parts: the office and logistics section (with reception, office, logistics and maintenance areas) and the IT and technical section (the IT area is almost the equivalent of the technical area: inverters, cooling systems, backup generators, batteries, etc.).
- It is an extremely partitioned space with little programmatic variation. We never see spaces crossing the heart of the data center where the data cabinets (sometimes partitioned by the client with their own security systems) are; circulations and technical spaces surround the central storage spaces, sometimes with offices and a cafeteria.
- Mixed programs are rare.
- The technical equipment is more structuring than the other programs. The separation of spaces and temperatures plays a key role in the infrastructure's efficiency. Climates are isolated and milieus created: cold lanes, warm lanes, climate rooms, exhaust flues (Vantage), space for the backup generators, various vats and tanks, the cooling towers, the inverters, the battery rooms, the control room.

As for architecture practitioners, the interest in taking on the new program – the data center – is recent. In fact, if the digital and cybernetics nourished the architectural and urban imagination of many groups in the 1960s, like Archigram and its famous "Computer City," there is no trace of storage spaces that were integrated at this period into computing spaces. Since the early 2000s, a few agencies have been developing real expertise on the question, like Gensler and CAC Architecture in the United States and Enia Architectes, DK Architectes, Reid Brewin Architectes in France.

Data centers are extremely sensitive objects for the clients (in terms of security, accessibility and continuity of the electricity service) and there is consequently a rather conservative character and a form of resistance to anything new. Experimentations or energy or programmatic boldness (like the hybridizing of these infrastructures with other types of uses such as offices, residences or cultural facilities) remain very rare.

Uses and mixed programs: beyond the building-machine

Data centers are above all designed to host servers, but new uses connected to their hosting activity are included in certain cases. The more advanced hybridizing possibilities in new buildings are very often theoretical. They are more the result of the evolution of an existing building as in New York where former telecom buildings have offices, data centers, radio stations, training areas…

For colocation data centers: a complementary offering
These installations created very few direct jobs: a dozen or so in a 20 MW colocation installation for example. On the other hand, there is a daily turnover of clients that work on their servers or deliver new material. Colocation data centers therefore systematically propose offices (clients and full-time personnel) and meeting rooms. Certain actors of the market stand out from the competition by offering a greater diversity of spaces and services: workout room, game room, conference room…

Figure 6. Equinix interior. Credits=© Equinix.

For hyperscale data centers: the digital phalanstery?

Data centers dedicated to Big Tech or companies reflect their own organizations and priorities. In Prineville, the two Apple and Facebook sites have 400 direct and indirect jobs. The Facebook data centers have a company restaurant, a fitness center, beds for personnel in case of work-related strain, meeting rooms, conference rooms, a billiards space, video games area…

Corporate data centers: between dedicated installation and combination with head offices

Many companies, notably those of the CAC 40, banks and insurance companies, built their own data center, generally including offices and meeting rooms, like BNP Paribas in Bailly-Romainvilliers and Crédit Agricole in Chartres. Certain corporate headquarters also include several levels in their stories for their own data center, in the end, perpetuating an old situation in which companies had computer rooms and cabinets onsite, but optimizing them and building them with current efficiency standards. A large number of companies with their head office in Paris La Défense have their own data centers in their building, with a backup on a second site. The New York Times in New York has done likewise (with a backup in Seattle). The American Gensler agency constructed a building in China, in Chengdu, whose base is a data center, on which the office floors of China Pacific Insurance (Group) Co. rest.

Figure 7. Data center designed by Gensler in Chengdu. Credits=© Gensler, 2017.

The data centers in Grand Paris express metro project
The Société du Grand Paris, implementing the new metro network construction, has initiated a completely new type of project in terms of hybridizing programs and land opportunism. It concerns small and intermediate data center projects in civil engineering works in the immediate vicinity of train stations (notably tunneling), that would have unoccupied spaces but also an electricity supply (usually solely used for the metro), and fiber that will be stretched along the tracks, on which every 800 meters, on the 200 kilometers of the metro network, there can be a connection, and with a double fiber network for redundancy. Each one would have an area of 250 to 1,000 m², intended for SMEs and local administrations. The construction and management modalities are being studied with the Caisse des Dépôts et Consignations (public investment bank) and private partners.
With this proposal of a semi-buried object, operating autonomously from the train station, the data center will take part in renewing the station concept and optimizing complex technical spaces.
The same is true for the future "Chapelle International" district in Paris, which will be delivered in 2021 and will host the data center of the city of Paris. The backbone of this new district (900 apartments in total, 33,000 m^2 of offices, a gym, a daycare center, an elementary school…) is an enormous logistics platform built along the tracks in northeastern Paris on an abandoned train yard. The subsidiary of SNCF Immobilier, Espaces Ferroviaires, is the sector's developer.

2.3 Urban concentration of flows and geographic decentralization of stock

The diversity of data centers, and their siting and operating criteria has led to an image of their spatial effects that is sometimes hard to decipher. A dual movement of concentration and dispersion consequently impacts the territories.

On one hand, the strong development of the gigantic data centers (hyperscale) that echoes the growing and disparaged concentration of the data of billions of people (2 billion for Facebook for example) by GAFAM and BATX[47] in China has been observed. These data centers are not located where the populations are concentrated but where land and energy are inexpensive. On the other, colocation data centers are concentrated in metropolitan spaces, near Internet backbones and Internet Exchange Points, ever closer to each other to limit the costs of connection to optical fiber. We could thus conclude that there is an urban concentration of flows through colocation data centers that are also entrances to Clouds and a geographic decentralization of stock with hyperscale data centers. In short, everything is converging on the city and the rural territory are spaces serving mass storage.
If we look back in time, the Internet was originally designed as a distributed network, first aiming at enabling researchers to easily communicate with each other, but also to make American military installations more resilient, especially faced with the possible and so dreaded nuclear attacks during the Cold War. This decentralized character then aroused utopic visions in which the cities would dissolve and spatial hierarchies disappear with the end of constraints connected to proximity. But finally, and from the beginning, the network was sited on strategic points in the city. Next came the existing networks. The Internet network first borrowed the telephone network, then optical fiber was inserted into the existing sheaths, along highways (France), metros (Paris), railroad lines; or overhead with the electricity network (like the high-voltage network of Bonneville Power Administration [BPA] in the American Northwest or with RTE in certain French rural territories). In this way, following an already existing path, the Internet reinforced the urban hierarchies already in place, the cables being joined in San Francisco, New York, Paris, London, Amsterdam, Frankfurt, economic capitals and metropolitan centralities with worldwide influence.

This apparent contradiction, between concentration and dispersion, seems to conceal several elements. The Internet network and information flows follow urban hierarchies, and favor metropolitan hubs, but inversely, at the beginnings of the Internet (and before the Web), the contents were decentralized, hosted in each computer, peer-to-peer. It was especially with the development of the commercial Web in the late 1990s that the hosting of sites, e-mail and company platforms, among others, led to increasingly colossal storage needs. Consequently, data centers mushroomed, in particular starting in the 2000s. The trend has continued at an impressive pace ever since.

[47] BATX: Baidu, Alibaba, Tencent, Xiaomi.

Nonetheless, behind this concentration/dispersion binary movement, and with the development underway and to come of edge data centers and regional data centers, it is a whole complementary system that is being established, adapting to the multitude of uses and needs of an increasingly digital life.

2.4 Camouflaged in existing building and in city centers

The city centers, in the United States as in Europe, and the international cities like London and New York to an even greater degree, have very high population densities and employment, and a concentration of exceptional wealth. These territories are strategic hubs where Internet cables are found and are connected; global and centralized decision-making centers where multiple information contents (cultural, financial, communicational, commercial…) are produced, consumed and distributed. The former telephone company sites often became Internet Exchange Points, accompanied by areas dedicated to data storage.

From the telephone to the Internet, the second life of connected buildings

In New York, several buildings in Lower Manhattan have continued, with the Internet, their communication destinies. The city of New York opened its doors in the late 19th century to the head offices of large telegraph and telephone companies. In 1914, AT&T and Western Union (telegraph) moved together to 32 Avenue of Americas, into a building constructed to the glory of worldwide communications, notably illustrated by the mosaic on the ceiling of the lobby, on which an allegory connects each corner of the map: Oceana, Africa, Asia and Europe (the US being at the center).
In 1928, Western Union moved a few hundred meters away to 60 Hudson Street, and had its head office built by the same architect who designed the AT&T building, in the Art Deco style.

Figure 8. 32 Avenue of Americas and 60 Hudson Street. Credits=© Cécile Diguet and Fanny Lopez, 2018.

The two buildings are connected by an underground conduit, now used for a phenomenal Internet traffic. In the late 1990s, the two buildings opted for the digital and the departure of their former occupants, and underwent an impressive molting, getting rid of their telephone installations to install Internet Exchange Points, data storage spaces and cutting-edge telecommunication infrastructures.

Since the terrorist attacks of September 11, 2001, but also a month earlier, when the urban steam network explosion that altered the entire IT system of Goldman Sachs in Lower Manhattan, the financial data centers, under pressure from the federal government, started to relocate to nearby New Jersey. The others quickly following including that of the New York Stock Exchange, which since 2010 has rolled out nearly 40,000 m^2 in Mahwah, in the northeastern part of the NJ state. These data centers also offer spaces for trading companies, which are therefore premium locations in terms of latency (each nanosecond counts). Added to that high energy as well as real-estate prices, but also a strong climate vulnerability as Hurricane Sandy demonstrated in 2012, with the shutdown of operations on several data centers, New York is a city where one has to be to be connected to hundreds of telecom networks, to have an entrance to Clouds, but everything has also shifted much farther: to New Jersey of northern Virginia in particular where energy and space are less expensive

A specific case, the Sabey tower is a recent development that runs counter to this trend. The New York Telephone Company built a telecom tower in 1975, at the foot of the Brooklyn Bridge, to house a telephone exchange. The company was then transformed into Bell Atlantic, then Verizon. Taconic Investors bought the building in 2007 (for $140 million), the 2008 crisis stopped their transformation project, and Sabey bought the building in 2011 (for about $100 million) that it renamed Intergate Manhattan, with Young Woo and Associates (a New York developer). Verizon still occupies three stories of the building today.

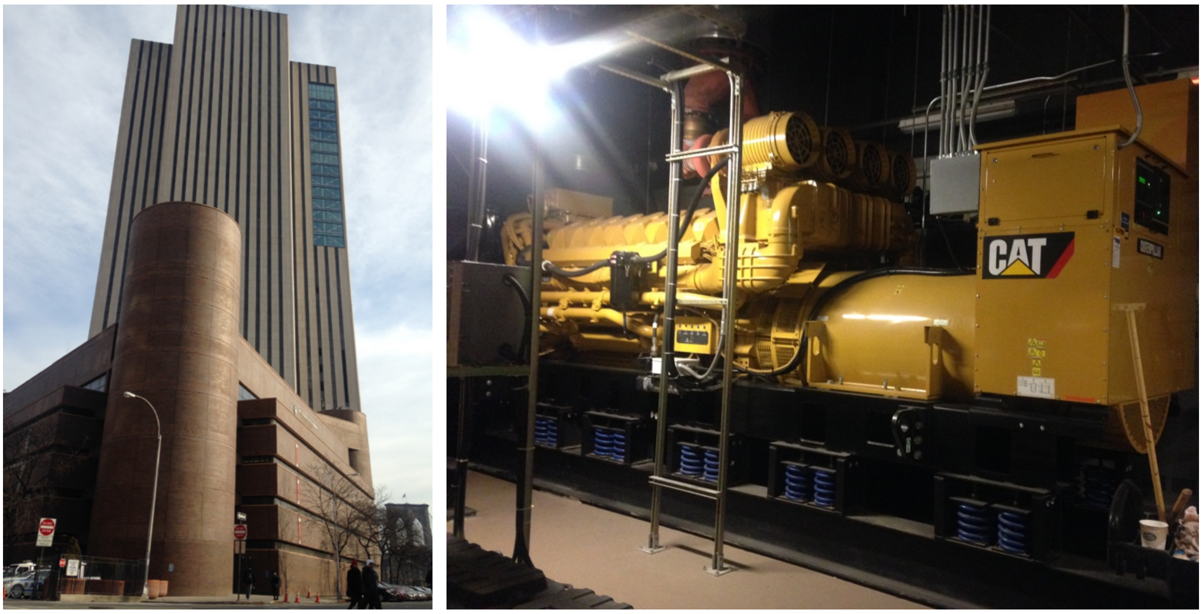


Figure 9. Sabey tower. Credits=© Cécile Diguet and Fanny Lopez, 2018.

Sabey is a Seattle-based real-estate company that built a great deal for Boeing, warehouses, factories, hangars; it then specialized in “critical facilities” for healthcare, the military and data centers. This 32-story building (160 meters high) offers an available area of 102,000 m^2. The ceilings are high (between 4 and 7 meters according to the floor) and each level proposes 3,600 m^2. Sabey invested $300 million to renovate the building. The power usage effectiveness (PUE) of their data center is 1.25. The temperature aimed at is 26.5°C, much higher than many other data centers. The other hosts and operators at Intergate have different strategies.

The transformation of these buildings initially constructed for and dedicated to communications is very specific to New York. Their design enabled their transformation:

- Heavy loads supported by the floors (weight of the servers);
- Offer of large open spaces and large areas on the building’s scale;
- Generous technical spaces;
- Large height also facilitating the operation of telecommunications antennas.

Three subjects are particularly interesting here:

- The recycling of existing buildings;
- The infrastructural compactness of these machine-buildings, in the very center of the city, containing all the infrastructures needed for their autonomy: fuel, water, cogeneration, thermal storage;
- The mixed use of the buildings: for example, at 32 Avenue of the Americas, offices, radio station studios, data centers and 70 telecom operators (30% of the area) and the head office of the Tribeca Film Festival coinhabit on a total area of 186,000 m².

The transformations: New-York, Portland, Paris

Other than telecom buildings, other old industrial, military, service and residential structures have also been transformed to house data centers.

In New York, an emblematic Internet building is 111 Eighth Avenue in the Chelsea neighborhood. The fourth large building in terms of area in New York, it is in reality a building-block of nearly 275,000 m^2, used each day by 7,000 to 8,000 thousand people, and whose diesel oil reserves of 600,000 liters ensure resilience in the event of a power failure. This former head of office of the Port Authority, built in 1932, was bought in 2010 by Google for $1.9 billion, with its renters, including many telecom operators and data centers. Failing to evict all of them, the company still shares the premises with some of them, which made Stanislas Voronov, manager of the Equinix site, say that their visibilities for the future is extremely difficult. He also described how, in 2010, faced with pressure from Google, many renters thought that the company wanted to become a telecom company given that “one-eleven” is an ultra-connected building. Their resistance finally pushed Google to rent additional offices, across the street, at 85 10th Avenue, where there are other data centers like Telehouse (but also the FBI).

Figure 10. 111 Eighth Avenue, Chelsea, New York City. Credits=© Cécile Diguet and Fanny Lopez, 2018.

In Portland, the Pittock Block is located in the very center of the city and is the nerve center of telecom networks and therefore of the Internet: the Portland NAP is located there. Many companies in the digital sector occupy this historic early 20th-century building. Initially constructed to house the first electricity plant of Northwestern Electric Company, “in the basement,” and other companies on the other floors, the building underwent a successful digital conversion.

Figure 11. Pittock Block, Portland. Credits=© Cécile Diguet and Fanny Lopez, 2018.

In Paris, the former telephone exchanges of the PT&T post offices have undergone very little digital transformation compared to New York since the real-estate heritage of the early 20th century has mostly disappeared to be replaced by new sites built in the 1970s. However, despite the data center grouping policy undertaken by Orange, there are still several locations in Paris, notably Montsouris aerial bunker (14th arrondissement) that is partially a data center. It should be pointed out that the principal Internet Exchange Points were not located here at the start of the Web. Today, they are therefore installed in facilities of the colocation leaders: Interxion, Equinix, Telehouse… and are located in Paris (11th arrondissement) (Voltaire), Aubervilliers, Courbevoie and Pantin, for example.

Figure 12. Data centers in central Paris: Telehouse, 32, rue des Jeuneurs; Telehouse, 137, boulevard Voltaire; Zayo, 19-21 boulevard Poissonnière. Credits =© Google Map.

On the other hand, the spaces historically connected to the telephone were located around Opéra and the Bourse,[48] to meet the needs of the press, banks and textile companies in the late 19th and early 20th centuries. This high level of connectivity was perpetuated with the Internet, and the Sentier district, also called for a time “Silicon Sentier”, is the site of several large data centers that were able to move

[48] Bertho Catherine, “Les réseaux téléphoniques de Paris – 1879-1927,” in *Réseaux*, vol. 2, no. 4 1984, p. 25-53.

into old adapted industrial buildings. The data centers located in the heart of Paris are therefore more transformations of formerly industrial buildings.

- The operator Telehouse moved, in the 1990s, into a building on the boulevard Voltaire, to no. 137, near the town hall of the 11th arrondissement, with a total area of 7,000 m^2 and available power of 5 MW. Until the 1980s, this building housed a department store, a competitor of Printemps and Galeries Lafayette, Paris-France, explaining the sturdiness of its structure. Nothing today indicates the presence of a data center. However, it is the nerve center of the French Internet: it house the France-IX Internet Exchange Point, and is the central hub for 80% of direct Internet traffic in France. One hypothesis for this siting is also the early installation of optical fiber in the neighborhood since the first link in France was created between the PTT telephone exchange of the Tuileries and that of Philippe-Auguste in 1982. Telehouse is also present in the Sentier district, at 32, rue de Jeuneurs, with 1,000 m^2 in the former Hôtel d'Agoult-Chalabre, a historic building with a metal structure built in 1871.

- The operator Zayo is close by, at 19-21 rue Poissonnière, with 1,250 m^2 (available power of 600 kW), also in a late 19th-century building with a metal structure, typical of the area, developed for textile merchants and the press at the period.

- Free's data center operator, Illiad, bought, in 2012, the laboratory building of the Ponts et Chaussées engineering school, located on the boulevard Lefebvre in Paris (15th arrondissement), which includes a bomb shelter 27 meters underground built in 1949. The bunker was supposed to house at the time the Ministry of Transportation in the event of an attack, in order to organize land communications. It now houses an 8,000 m^2 data center.

- In Courbevoie, near La Défense, SFR installed a 12,000 m^2 data center in the former Delage automobile factories, built in 1912 on 15 hectares. The enormous brick and metal building with saw-tooth roofs will be the sole heritage marker when the urban project underway on the Delage village is completed.

The industrial heritage has thus made it possible to ensure a large degree of connectivity and a digital hosting capacity in the heart of Paris and in the immediate vicinity of its business districts (8th district and La Défense in particular).

The buildings specifically constructed to house data centers in very dense urban fabrics are much rarer, given the complexity of building in them, and the priority often given to housing and activities that create much more employment, but especially the ease, in comparison, of developing in more adapted territories, with fewer urban, environmental and proximity constraints. We find them more in the metropolitan peripheries of the digital.

2.5 The metropolitan outskirts of the digital

Metropolitan outskirts, often industrial in the past, are ideal siting places for colocation and Cloud data centers, and for local companies that need a low latency. There is a common development model: a formerly industrial territory, often serving the metropolis, offers large footprints and a large amount of electrical power, but also good connectivity (optical fiber followed highways and railroad lines, often crossing these territories): data centers then replace factories. Is this the perpetuation of this service character or a rise in range? Each territory relies on their arrival in a different way. Santa Clara, in the heart of Silicon Valley, made them an economic development lever and a major source of financing for the city's operation via its municipal electricity company. Saint-Denis and Aubervilliers, just north of Paris, seem to have had this development more imposed on them, while the city of Hillsboro, next to Portland (Oregon), negotiated the relocation of its electronics industries.
Accentuating the mono-functional nature of the economic territories in which they are sited, appearing similar in terms of landscape to logistics or commercial zones, these digital activity zones contribute to urban fragmentation, with very large plots of impenetrable land, often ultra-protected by defensive fences, not bringing any major degree of urbanity to the territories. Certain examples of successful integration are however to be stressed like the project of the Chapelle International district (presented above), on a former railyard in Paris, which includes a data center in its logistics section.

Plaine Commune or the opportunity for deindustrialization

The Plaine Commune urban area is located north of Paris in the Seine-Saint-Denis department. According to Alain Vaucelle, ICT representative for Plaine Commune, it has about 20 data centers. According to Fabrice Coquio, president of Interxion, the number is more on the order of 47 data centers on 25 km^2 of territory.[49] With regard to the secrecy surrounding these infrastructures, the figures differ according to the actors queried, but Plaine Commune remains the French territory with the greatest concentration of data centers, notably in the cities of Saint-Denis and Aubervilliers inside Plaine Commune, with respectively five and eight data centers listed.

The presence of data centers in Plaine Commune dates to the late 1990s. The first colocation data center of Plaine Commune was installed in Aubervilliers, in the Portes de Paris park, and was opened by Interxion in 1999. The presence of very large plots of land at affordable prices in the immediate vicinity of Paris, and the good availability of electricity, witnesses of the industrial past of Plaine Saint-Denis, favored the development of these colocation data centers at a time when development in Paris was becoming limited. We must also note the quality of the connectivity with the presence of one of the main Internet backbones along the A1 highway that enables the different European data centers to be linked to each other. Moreover, as it is in the data centers' interest to be grouped to pool and optimize the dark fiber networks,[50] they created pockets of concentration on the territory, in particular in the southern part of the urban area.

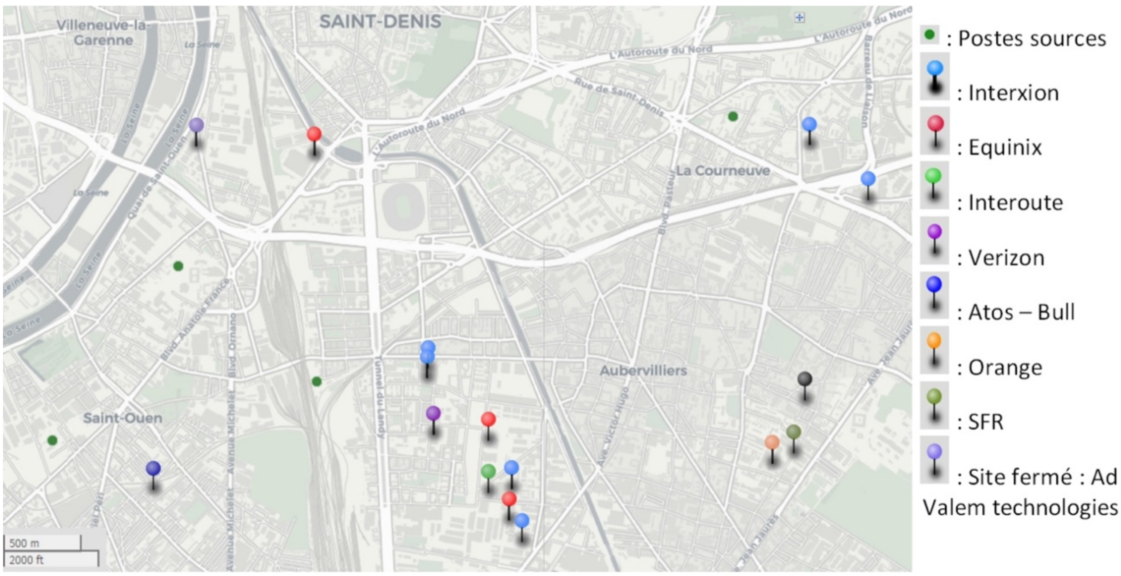


Figure 13. The data centers in Plaine Commune. (background: open street map; data: ENERNUM)

[49] It should be recalled that the data for corporate data centers are difficult to access and sometimes vague: while some people count data centers that can have several buildings, others will count each building as a data center. Certain people can also talk about colocation data centers without specifying them, whereas there are also corporate data centers.

[50] In fact, the installation cost of dark fiber amounts on average to nearly €1,000 the meter (F. Coquio, March 2018). Consequently the more concentrated data centers are, the lower their connection costs.

Company - data center	Date of construction	Commune - street	Area (m²)			Max. IT power (MW)	Total power available (MW)
			Plot	Floor area	IT		
Interxion PAR 1	1999	Aubervilliers, avenue Victor Hugo	3,300	2,250	1,450	1,3	4
Interxion PAR 2	Entre 2000 et 2005	Aubervilliers, rue des Gardinoux	5,525		3,000	4,5	12
Interxion PAR 3	2007	Saint-Denis, avenue des arts et métiers	4,781	4,123	2,000	5	15
Interxion PAR 5	2009	Saint-Denis, avenue des arts et métiers	6,027	7,433	4,200	10.55	30
Interxion PAR 7	2011 - Extension 2018	La Courneuve, rue Rateau	18,293		9,000	30	64
Verizon	2001	Aubervilliers, rue de la Montjoie	7,822	4,500	3,000	2,25	6.75
Equinix PA 2	2007	Saint-Denis, rue Ambroise Croizat	56,340	54,597	6,300	10	30
Equinix PA 3	2007	Saint-Denis, rue Ambroise Croizat			6,700	11	30
Equinix PA 5	2007	Aubervilliers, rue Victor Hugo	2,310		1,250	2	5
Equinix PA 6	2008	Aubervilliers, rue Waldeck Rochet	10,700	14,000	4,600	7.4	28
GTT - Interoute	2003	Aubervilliers, rue des Gardinoux	6,517		760	1.3	4
Atos 3	2009	Saint-Ouen, rue Dieumegard			3,600	5	15
SFR netcenter	2011	Aubervilliers, rue de la motte			600	1	3.5
Orange		Aubervilliers, rue de la motte			2,000	4	13
Interxion PAR 8 (project)	Under construction	La Courneuve, Avenue Marcel Cachin			40,000		100
Total					84,460		**260.25 MW (+100 MW INT PER 8)**

The data centers in Plaine Commune, October 2018.

The calculation hypothesis to extrapolate the missing data from the table are provided in the annex (Extrapolation/Sourced values)
For the SFR and Orange data centers, the calculations were made using data collected from their backup generators.

We identified 16 data center sites for seven operators with Equinix and Interxion, the European leaders of colocation data centers, in the lead with respectively four and five data centers.

The data centers in Plaine Commune are mostly large data centers, in a relatively heterogeneous urban environment, with an average area between 1,000 and 5,000 m². In addition to the future Interxion data center in the project stage in La Courneuve (Eurocopter site), there are also two very large data centers: Interxion's other La Courneuve data center being extended on the rue du Rateau, which should reach 9,000 m² of IT rooms and the Equinix data center in Saint-Denis (PA 2 and PA 3 are in reality on the same site) with 13,000 m² of IT rooms on the plot of almost 6 hectares.

There are thus over 84,000 m² that will be occupied by these storage infrastructure in Plain Commune when the Interxion data center (Eurocopter) will be completed, with over 360 MW of dedicated electrical power.

A slowdown in the number of data centers built was observed starting in the early 2010s, a phenomenon that can be explained by three main factors:

- Land was no longer as available or inexpensive as in the 2000s, notably because Plaine Commune continued a development and significant urban transformation dynamic, with the creation of the Campus Condorcet, the arrival of metro line 12 at Front Populaire and the residential developments north of the Entrepôts des magasins généraux de Paris.

- The colocation sector was consolidated and the different operators had recently bought several companies and existing buildings. Consequently Equinix, the worldwide colocation leader, purchased companies like Telecity and data centers like those of Digital Realty Trust and Verizon.

- During the construction of the Plaine Commune large data centers, the operators decided to anticipate the growth of the market. The size of the installations built therefore did not correspond to the real needs of the operators who projected additional spaces to rapidly meet the clients' demand. Some of them therefore remained empty and were gradually filled.

If the 2013 ALEC study had warned local elected officials about the data center phenomenon and made the subject a priority on the eve of the 2014 municipal elections, mobilization has somewhat weakened since this time. This is notably due to the slowdown of the construction rhythm of these storage infrastructures but also the many large project in which Plaine Commune is now involved (2024 Olympic Games, urban renewal, Grand Paris Express metro system). The question has thus been little discussed on the intercommunal scale, whereas other subjects are the focus of working groups between communes.

Nonetheless, the metropolitan area has realized that data centers raise a threefold question:

- The durability of the local electricity system. Enedis (national monopole for the electricity distribution) is building a new source substation that should be finished in 2019-2020 in Aubervilliers, near the Campus Condorcet, in order to better meet connection needs.
- The appearance of possible environmental disturbances for the inhabitants (the Interxion data center on the rue Rateau in La Courneuve was the object of very strong citizen opposition): noise pollution, danger linked to diesel oil storage, electromagnetic waves.
- The large impenetrable spatial footprints of data centers, for a very low number of jobs.

The Eurocopter site: looking for an understanding
The Eurocopter site is an illustration of these questions and the difficult dialogue between actors. The Interxion group is currently initiating a data center project on a plot of 6.3 hectares, in La Courneuve, on the site of the former Eurocopter helicopter factory. When the departure of Airbus-Eurocopter from the factory, at 13, avenue Marcel Cachin was announced, the site was immediately bought by a local investor, without the local administration exercising its urban pre-exemption right or having the land taken over by Établissement Public Foncier d'Île-de-France in order to control is evolution. The site is

located near the city center, opposite public facilities (sports, high school) used by many of the city's inhabitants, in a context that is currently hostile to pedestrians.

Figure 14. Eurocopter site. Credits=© Cécile Diguet and Fanny Lopez, 2018.

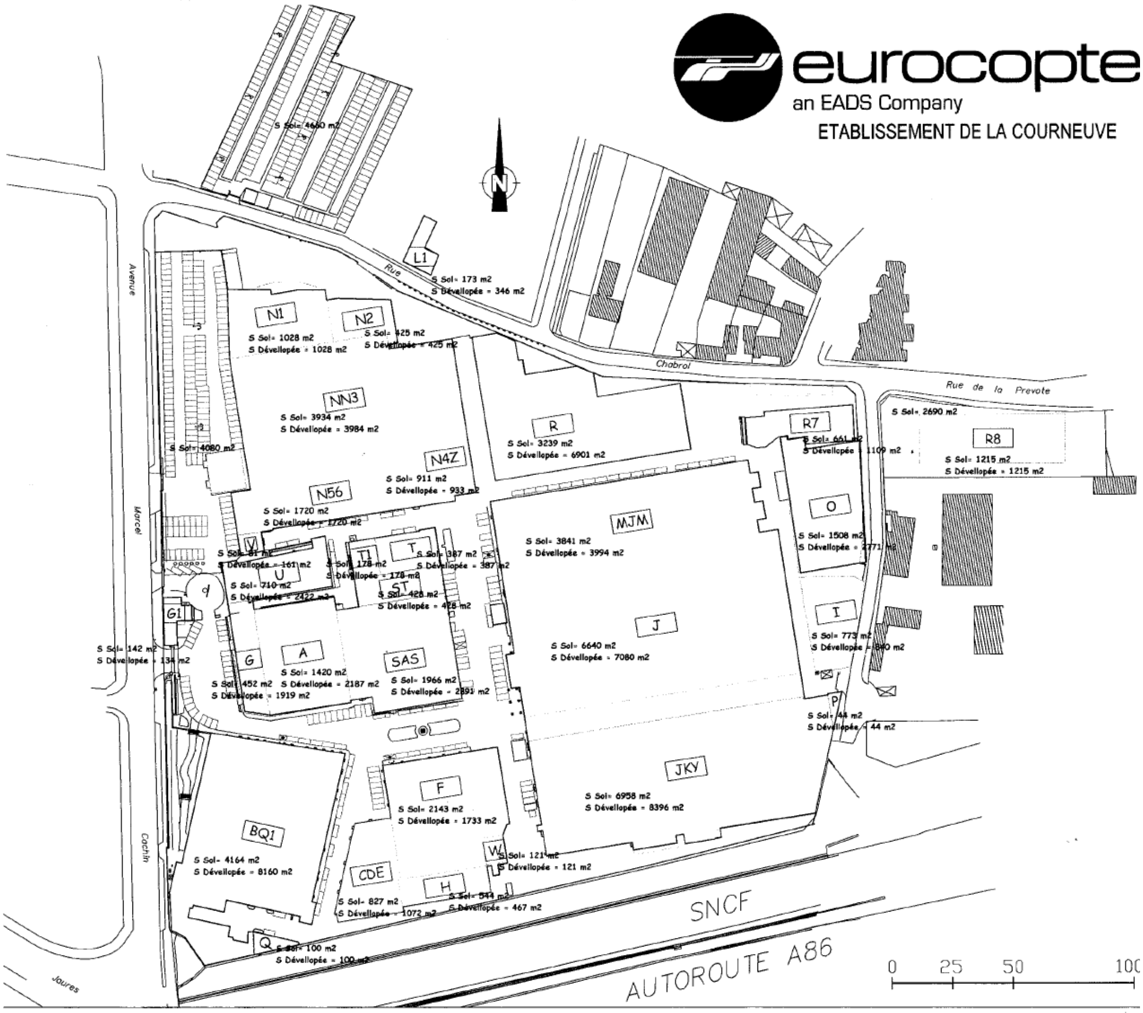


Figure 15. Plan of the Eurocopter site. Credits=© Eurocopter

An agreement on a lease whose duration we do not know was then concluded between the new owner and Interxion to develop a data center project. A first building permit was filed in 2013 by Interxion for the construction of a data center on only part of the site, representing an area of 4.2 hectares, in accordance with Plaine Commune. This project, discussed with the commune and the metropolitan area, planned for the development of two spaces presented in a study by the Anyoji et Beltrando agency[51]:

[51] Anyoji et Beltrando agency, *Cahier de prescriptions urbaines, paysagères et architecturales, étude de programmation urbaine et économique*, December 2012. Municipal archive department.

- Along the highway, the Interxion data center;
- In the northern part of the Eurocopter footprint, separated from the data center by a new road, an urban development with housing units, thought of in interaction with the Chabrol sector (13 hectares), its existing facilities (football stadium, dojo) and other new apartments.

The local urbanism plan of La Courneuve duly noted this project and zoned the site according to the uses decided. The Plaine Commune metropolitan area was a stakeholder to accompany the commune in this discussion with the operator. After the delays of the move of Eurocopter's installation, Interxion filed a new building permit in the summer of 2018. This new project no longer aims at urban integration and goes back on the negotiations conducted with the local administrations, since it plans to develop a data center on the entire 6.3-hectare plot.

The Eurocopter site is particularly interesting for a data center operator and seems to constitute, according to the CEO of Interxion, one of the last major real-estate opportunities in Plaine Commune. Apart from its size, and its connectivity (optical fiber along the A86 highway), the presence of RTE[52] electricity lines that border the plot (along the railroad tracks) is strategic. It would thus be possible to directly connect to the RTE network and not have to rely on the Enedis distribution network. The power requested for this data center would be 100 MW,[53] for 40,000 m² of IT area. Today, Plaine Commune wishes to improve the project's integration and started new discussions to improve the interface between the new constructions and the city: fences, entrances, vegetation, but also to obtain an urban façade with openings for the building.

Whereas Interxion could have played the game of a shared project, improving the Chabrol sector's urban functioning, in this way indirectly contributing to the regional housing construction effort, to a better porosity of the urban fabric, it is, on the contrary, blocking any change.

On the other side of the Atlantic, municipalities have taken a different approach to the development of these building.

Hillsboro: IT activity zone, from electronics production to data storage

Hillsboro is a city in the Portland suburbs, a few kilometers west of the capital of Oregon. Its economic development was backed by the arrival of Intel (and before Tektronic) in the 1970s, then a host of electronics subcontractors. Intel is the territory's historic actor and produces its processors there. It is also the largest employer in Oregon (19,000 jobs). The city is therefore very dependent on the IT industry and concentrates 41% of all the jobs in the digital sector in Oregon. The data center industry is also very present there, with about 15 of them concentrated in the northern part of the city, which is continuing to develop on increasingly larger areas with QTS and Digital Realty, for example. The French company OVH moreover opened an installation in early 2018, but there is also LinkedIn hosted at Infomart, the Adobe software company, Tata, Flexential, Edge Connex data centers as well as others. The oldest data centers were installed in former electronics factories, the most recent are new constructions.

Data centers first arrived in Hillsboro in the 2000s and continue to be installed there for several reasons.

Structural strong points:

- As everywhere in Oregon, abundant and inexpensive energy thanks to the hydroelectric dams on the Columbia River;
- Electricity infrastructures already well-calibrated for Intel, a great deal of available power, and two new substations being built by Portland General Electric;
- A strategic position on the trans-Pacific cables and between the north and south of the West Coast, and between Portland and the Pacific Ocean. This situation even improved in 2018. Mark

[52] RTE is the national monopole for electricity transmission

[53] Interview with Fabrice Coquio, president of Interxion France, March 6, 2018.

Clemons,[54] the then city's economic development director, stressed that 75% of the bandwidth of the new trans-Pacific cables under construction was to arrive in Hillsboro in 2018, strengthening its strategic position of the Internet network hubs.

- Affordable and available land, through the use of former farmland (easy to urbanize). The city did not have a lot of trouble broadening the UGB (Urban Growth Boundary) to offer new buildable areas, for industrial uses, provided that jobs are created. However, protest from the state of Oregon and Portland Metro is growing due to the low rate of job creation and spatial sprawl. Data centers are slowly nibbling acres of truck farming land whereas many abandoned industrial and port sites could have housed these digital infrastructures in Portland. Hillboro's connectivity on one hand and tax exemptions on the other have consolidated this situation over time.
- Transformable buildings: former electronics production plants of the Epson type are now occupied by Flexential, the Infomart building, and the former paint factory by OVH.
- A temperate climate, favoring free cooling.
- Access by the highway, and the presence of an airport in the immediate vicinity (non-commercial flights, 32 private jets for the link to Silicon Valley in particular).
- The proximity of Silicon Valley (a 1-hour flight), where a certain number of companies present either for data centers (Adobe, LinkedIn) or production (Intel) have their corporate headquarters.

Tax incentives and proactive action of the local administration:

- Tax incentives:
  - Oregon is one of three American states that have no sales tax. The acquisition of all the IT material required for the data centers is therefore much less expensive.
  - The city created an enterprise zone that exonerates companies from property tax. But tax incentives through special economic zones now force data centers to create more jobs. The local press has moreover been the outlet of a certain number of questions faced with the granting of an extremely advantageous tax system for them whereas they only create very few jobs, often a dozen for a 20 MW installation, without counting construction jobs. Infomart, for example, was granted a 20-year property tax exemption when it arrived.

- Furthermore, the city offers a very warm welcome to business through its technical departments, which facilitate all the installation, development, contact and coordination steps with the electricity company, network utilities, the state of Oregon and Portland Metro. Hillsboro additionally created a working group dedicated to these one-stop services for data centers.

- Lastly, the activity zones in which data centers are sited are very carefully designed, as much by the city as the owners and managers of the business parks:
  - Generous vegetation, presence of a park, aligned planting…;
  - Bike lanes (but the street and road network is largely sized and very road-oriented);
  - Cleanness of the spaces.

[54] Interview conducted on September 18, 2017 in Hillsboro.

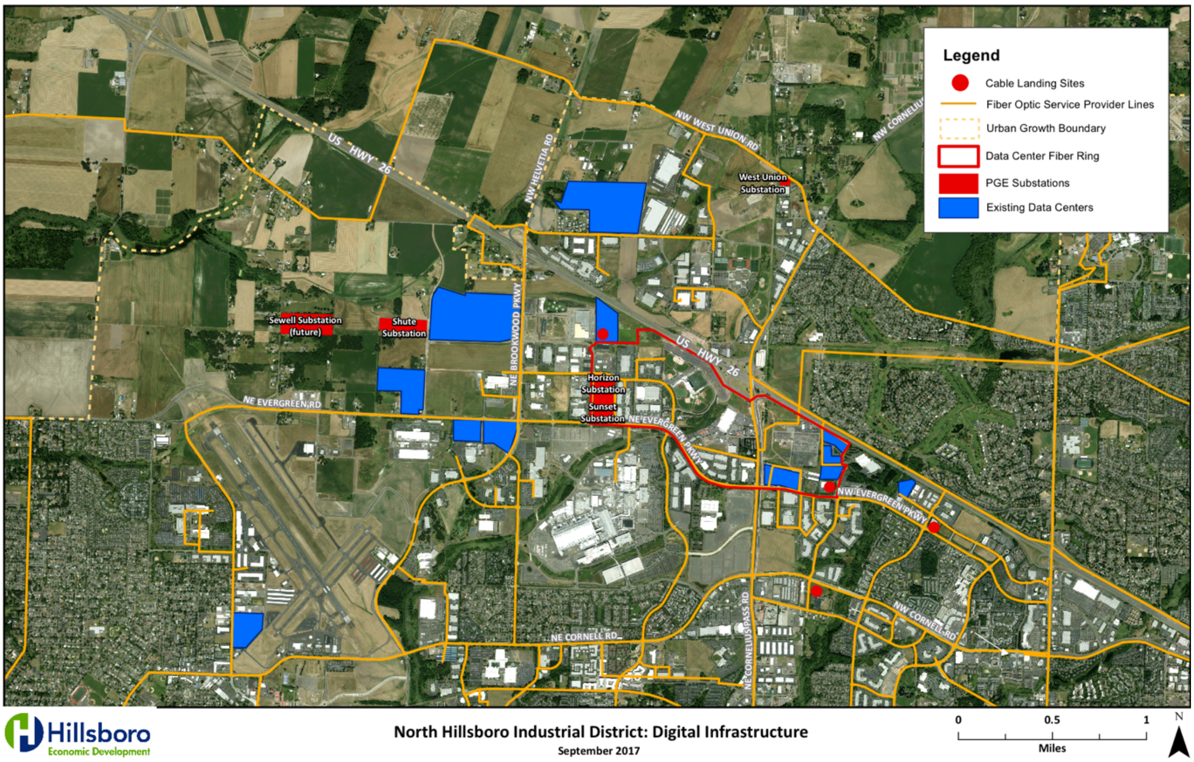


Figure 16 The digital activity zone. Credits=© City of Hillsboro, 2018

Figure 17 OVH and Adobe data centers in Hillsboro. Credits=© Cécile Diguet and Fanny Lopez, 2018.

The Infomart data center

One of the data centers sited in Hillsboro is that of the operator Infomart. It is located in the center of the city's activity spaces, not far from the Intel factory and the highway access, and alongside a BPA (Bonneville Power Administration) transformer station. Infomart has developed 32,000 m^2 of IT area, with dedicated power of 18 MW and a reserve of the same power to roll out when the data centers are filled. A the end of 2017, when we met Infomart VP, Paul Vaccaro, it was filled at 50% in terms of space, and uses 30% of the available energy. Its main client was LinkedIn, which occupied 30% of the building, and supervised the entire installation of its servers and technical systems to reach a PUE of 1.06. The temperature is for example higher than in Infomart's traditional colocation halls in the rest of the building: 22°C instead of 18°. In this way, the PUE objective for phase 1 is 1.4 but used at 30% it drops to 1.7. The same is true for phase 2 (extension) – projected at 1.06, it is currently at 1.2 with a 30% occupation rate.


Figure 18 Infomart data center, Hillsboro. Credits=© Cécile Diguet and Fanny Lopez, 2018.

The building is a former electronics production plant, with a technical floor that Infomart could use to install all its cooling equipment. An extension was added to it, designed by the same architect who had constructed the initial building (Jackson Main). Infomart's electricity supplier is Constellation, which provides it with 100% renewable energy (hydroelectric, wind and solar) through the Direct Access program. So the cost of energy was then 6.5 cents/kWh instead of 8 to 9 cents/kWh with PGE (Pacific Gas & Electric). One of the company's objectives for the future is to have energy that is as local as possible.

Silicon Valley/Santa Clara: over-equipment at the cutting edge of the digital world.

California is not the ideal destination for installations as strategic as data centers in terms of earthquake risks, the high price of energy (except in Santa Clara), land that is rare and expensive, but it is THE place to be. It is first of all where the largest actors of the digital world (Alphabet-Google, Facebook, Oracle, Apple, Salesforce) have their corporate headquarters, and many startups developing new products, software and services and therefore collecting, creating, processing and storing data. It is also a dense metropolitan zone (for the United States), with high income and developed digital practices, in short, a consumption and strategic prescribers basin. Silicon Valley therefore has an immense need for data centers, and certain territories consequently became its infrastructural back office.

Silicon Valley is the historic birthplace of the development of the Internet and IT in the United States. It extends, in a dense and congested urban fabric from San Francisco to San Jose with at the center Palo Alto, home of Stanford University, and host of a strategic and historic Internet Exchange Point for the West Coast (here at Equinix as well). The Palo Alto Internet Exchange (PAIX) is located in a former telephone exchange in the city center, near its most commercial street, University Avenue. But it is the city of Santa Clara that concentrates the largest number of data centers: 50 or so consume the energy supplied by the municipal public electricity company, Silicon Valley Power, and represent 80% of its revenue. Whereas the center of the valley (Mountain View, Palo Alto, Cupertino, Sunnyvale) houses offices and campuses of high-tech companies, the southern end of the valley, Santa Clara and San Jose in particular, concentrate storage infrastructures.

This territory, once covered with truck farms, was called the "Valley of the Heart's Delight" for its flowering orchards. It industrialized throughout the 20th century, with the concentration of canning plants linked to farm productions, then, especially, with the postwar development of military and computing research. Santa Clara therefore became a production city based on electronics and semi-conductors. The corporate headquarters of Intel is an heir to this industrialization and processor manufacturing moreover moved to Hillsboro, Oregon. The territory has always offered decisive electrical power, oversized networks notably for sanitation, large plots of land, now sold at astronomical prices, but above all the cheapest electricity in all of California. This advantage, undeniable for the data center industry, pushed these infrastructures to cluster there in the 1990s, transforming the former electronics factories then constructing their own buildings, ever more discreetly but surely. The city of Santa Clara consequently benefited from a strategic choice: that of having created its own power company in 1896, whose production units, notably hydraulic, have long been amortized. It also supplies a dark optical fiber network to companies, completing a perfect offering for the digital world.

If they perpetuate, in a certain way, their role as a territory serving the metropolitan heart and decision-making centers, Santa Clara and San Jose are also home to many activities: the service sector, corporate headquarters, universities, offices, large-scale sports and cultural facilities.

Today, available land is starting to become rare in Santa Clara and the space dedicated to data centers competes with housing needs. Whereas they were often in industrial zones, they are now in office zones, which illustrates their mutation in terms of urban integration. They are therefore imagining more compact developments with more architecture, like the Vantage campus that built higher and densified its plot on Walsh Boulevard. On this former Intel site, initially containing a single data center, there are now five of them, and a sixth was recently delivered on an adjoining plot. The campus also has its own source substation. The limit of urban regulations on building heights is however 21 meters, a priori negotiable on a case-by-case basis according to the urban planning manager.[55]

Figure 19 Vantage campus. Credits=© Cécile Diguet and Fanny Lopez, 2018.

The city of San Jose, just south of Santa Clara, is consequently housing an increasing number of data centers: a Microsoft project has reached 40,000 m².[56] Equinix is developing a campus there, on the former IBM micro-processor plant and farmland. Central Valley (east of San Francisco Bay) and the city of Hayward (where an Amazon data center was built) are also being developed as a complement.

The city of Santa Clara has a proactive positioning to attract data centers and has several notable particularities.

- There is a favorable tax system for these industries despite the very few jobs they offer because the corollary of very few jobs is fewer traffic jams, a major problem in the valley.
- The electricity of the municipal power company is the least expensive in California. Moreover, the large energy consumption of the data centers enables the municipality to invest the profits in public services and local facilities.
- The municipality has its own firefighters and highly mobilized technical departments, with integrated processing of installation requests, therefore very rapid.
- The data centers are required to make an effort for a better architectural and urban integration, and the results are often less defensive than in France.

[55] Interview with Yen Chen, urban planner, head of the urban planning department, city of Santa Clara, October 12, 2017.
[56] http://www.datacenterknowledge.com/microsoft/report-microsoft-buys-land-silicon-valley-huge-data-center

The data center, consolidation of an obsolete model or a potential reinvention?

Do the outskirts of the digital or digital economic zones have exactly the same spatial effects as shopping centers and logistics zones?

It must first be noted that data centers are a hybrid between:

- Frankly industrial dimensions through the massive amount of electricity that is consumed by them and the fuel oil reserves stored, as well as the technical part of the building;
  and
- Service dimensions through the absence of physical problems such as dust, truck traffic, and for the newer and better designed centers, the absence of noise, but also the presence of offices and meeting spaces.

They thus include spaces like Plaine-Saint-Denis in which there are service, industrial and residential uses (this cohabitation is also explained by the mutations underway) as well as production and service spaces like Hillsboro and Santa Clara.

Here, it is more the accumulation of data centers that raises questions, insofar as it feeds a model (the activity zone) that seems obsolete in terms of the imperatives for fighting the effects of climate change, but also because it creates strong pressure on the local energy system.

These spaces all propose:

- Single-function territories that do not favor complementary uses, but minimize conflicts between uses;
- Large impenetrable footprints that are very mineral, rather hostile to pedestrians;
- Architectural objects of the “large box” type without any landscape or urban insertion;
- Buildings that quickly become obsolete, and are hard to transform.

Consequently, at a time when many French territories are trying, with difficulty, to densify and diversify their economic zones, to reconnect them to the built urban fabric, to make their obsolete buildings evolve, the fight against climate change implies:

- Favoring traveling by foot, therefore the porosity of built footprints and a dense road and street network, with small plots or blocks;
- Limiting the footprints of buildings so that the ground does not become impermeable (therefore better controlling parking), favoring water infiltration, biodiversity but also limiting the urban heat island effect aggravated by the heat discharged by data centers;
- Reducing land consumption through a greater mix of functions, a reasoned density, the transformation of what already exists;
- Decreasing energy consumption and favoring heat exchanges and energy solidarity when relevant.

The data center should be made a positive transformation vector of economic zones so that a model that is not relevant today to fight against climate change is not simply reinforced. This would therefore imply rethinking its architecture, its spatial, environmental and energy integration, its hybridization but also planning, anticipating, guiding the site logics of data centers, according to their diversity and their expectations.

2.6 Conquering the rural world

In the rural world and peri-urban territories, the issue is more that of sprawl, governance and of a solitary object incapable of integrating a local ecosystem.

Two Big Tech in Prineville, in the heart of Oregon

Oregon has positioned itself as a less costly, less risky and greener option than California because of its generous and inexpensive hydraulic energy produced by New Deal dams on the Columbia River, a great deal of available land, good connectivity, only a 2-hour flight from Silicon Valley. Google built its first data center in The Dalles in 2006. In Prineville, in a rural and desert territory, Facebook did likewise in 2009 and Apple followed in in 2011. These last two digital giants have continued to develop their installations: a third storage space for Apple is being completed and Facebook announced in December 2017 the construction of two new buildings. This will bring their number to five, for a future total area of 200,000 m^2 (the area of Terminal 4 at the Madrid Barajas airport or that of Grand Central Station in New York). Facebook's three façades are as long as those of the Château de Versailles on the garden side. Farther north, the state of Washington also produces energy from the dams on the Columbia River and the historic site of Amazon is in Seattle, and not far away, in Redmond, that of Microsoft, which has a data center campus installed in a rural village, Quincy, in the center of the state.

Figure 20. Apple and Facebook data centers, Prineville. Credits=© Cécile Diguet and Fanny Lopez, 2018.

Several points should be noted:

- The data centers arrived concealed without saying what they were. Facebook's code name was Vatas. The local administration only knew that the project needed 80 to 120 hectares, a lot of water and a lot of electricity. It had no idea on the other hand of this operator's activity at startup and until rather late in the project's progress. Big Tech's secrecy culture can thus run counter to the territories' need for urban and economic anticipation and planning.
- They were sited on the heights of the town, in a very heterogeneous industrial zone isolated from the rest of the town, and could not be seen from the center, on the town's request. The urban growth boundary was extended to satisfy their requests, but their constructions had to respect height restrictions to preserve the landscape (the rims*)*.
- In a town of 10,000 inhabitants, with an unemployment rate of 21% in 2008, these data centers were a windfall for employment:
  - In the building sector (continuing today with extensions underway);
  - For the sites' operation: Apple and Facebook represent 400 direct and indirect jobs (subcontractors, maintenance...).
- Facebook (more than Apple) is involved in the local community, through financing: free concerts in the park in summer, new IT tools for schools or scholarships, for an estimated total since its arrival of over 1 million dollars.
- The Apple and Facebook buildings are the reflection of their obsession with security and opaqueness: roads closed with concrete blocks, double fences, paired with ditches, video surveillance, guards continuously patrolling in cars…

- Between 2008 and 2017, the electrical power required in the city soared, according to the city's planning director,[57] from 10 to 500 MW. Facebook and Apple consequently co-invested in five 15 MW solar farms not far from their sites. Apple also invested in a micro-hydraulic dam project and each of them pays the annual project costs to install then develop, and contribute to investments in local infrastructures (source substations, water production and sanitation plants).

Amazon Web Services in Umatilla and Port Morrow

Still more discreet, even truly opaque, the worldwide leader of the Cloud Amazon Web Services (AWS) is building data centers at a frenzied pace throughout the world. From Port Morrow to Umatilla, always along the hydroelectric manna of the Columbia River, the company rolls out storage warehouses that resemble factories, in isolated industrial parks or rural no-man's-lands. No care is taken with the building, which could be taken for a food storage warehouse or a logistics platform, topped with imposing air-conditioners and hitched to large fuel oil backup generators.

Figure 21. Amazon Web Services, Umatilla. Credits © Cécile Diguet and Fanny Lopez, 2018.

Umatilla, a small dull town of nearly 7,000 inhabitants, created at the time of the gold rush in 1863, has housed American army stores of chemical weapons since 1962. It has its own municipal electricity company and could not say no to Amazon when the company wanted to install there. Julie Peacock,[58] of the Oregon Public Utility Commission, pointed out that small towns want data centers to be installed, but that this risks endangering their own electricity system. The power demand was such that the local electricity company committed to building new production units for which, on one hand, it would go into debt and, on the other, had to make the territory's consumers, whose means are very modest, bear the cost whereas nothing guaranteed that AWS would still be there five years later. The company consequently exerts pressure that can destabilize the territory's economic and energy balance.

[57] Interview with Phil Stenbeck, September 27, 2017, Prineville.

[58] Interview in Portland, September 20, 2017.

The digital transition of these rural territories raises questions because it makes these towns, here Prineville and Umatilla, very dependent on a small number of actors and they size their energy, hydraulic and road infrastructures for actors whose longevity is not really known.

Data centers in the fields: the broadened territory of Paris Saclay

The French-style Silicon Valley
The territory studied straddles two departments (Yvelines and Essonne) and four inter-communalities (Saint-Quentin-en-Yvelines, Versailles Grand Parc, Paris Saclay and the Pays de Limours). It comprises the scope of the Opération d'Intérêt National Paris Saclay, steered by the Établissement Public d'Aménagement Paris Saclay (EPAPS). A large number of transformations took place on this territory that now concentrates many research activities as well as those related to the digital, involving the presence of data centers. The EPAPS (a public developer) is notably in charge of the development of the "urban campus," which will in the end welcome 68,000 students and 11,000 researchers.[59]

It is comprised of:
- The Comprehensive Planning Zone of the École Polytechnique area;
- The Corbeville district that will welcome a "hospital of the future" in 2024;
- The Moulon district, which is developing around the siting of Centrale Supélec and buildings of Université Paris-Sud as well as the École Normale Supérieure.

The EPCI Paris Saclay includes the urban campus, developed by the EPAPS, as well as other zones in which data center operators are present, as in the Courtabœuf activity zone, one of the largest in Europe, and the cities of Les Ulis and Marcoussis.

This territory has undergone three successive development waves, each time consolidating its digital dimension with IT computing and data storage.

- The first installations on this campus were the CNRS (National Scientific Research Center) in 1946, the CEA (French Atomic Energy Commission and Renewable Energies) in 1952, the INRA (National Agronomic Research Institute) and the ONERA (National Aeronautical Studies and Research Office) in 1948.

- A second series of installations took place in the 1970s, notably the École Polytechnique in Palaiseau in 1976, the creation of Université-Paris XI in Orsay in 1971 and that of Supélec in Gif-sur-Yvette in 1975.[60] In 1992, a development and urban master plan was drawn up and planned for the development of 640 hectares for research. At the period, this project ran up against local opposition and distant support from the government.[61] In 2006, a national interest operation was created with the project of a French-style "Silicon Valley" that would bring together in one area 25% of all research activities in France. Two advanced research thematic networks emerged in the field of physics and information and communication sciences and technologies as well as two higher education and research clusters (UniverSud and ParisTech).

- A new movement was announced in 2009 with the successive arrivals of AgroParisTech, the ENS Cachan, the École Centrale and the ENSAE that wanted to join the campus. At the same time, EDF decided to transfer its main R&D center from Clamart to Palaiseau, next to the École Polytechnique. Among the projects currently underway, we can site DIGIHALL,[62] which brings together digital actors, researchers and companies on subjects related to digital technologies and artificial intelligence.[63]

[59] Pierre Veltz, *Petite ensaclaypédie*, Éditions La Découverte, Paris, 2015.
[60] Site of Université Paris-Saclay: https://www.universite-paris-saclay.fr/fr/notre-histoire
[61] Veltz, op. cit.
[62] Site of the EPAPS, http://www.epaps.fr/projets/tous-les-projets/nano-innov/
[63] The founding members of this project, with plans to have 1,500 researchers, are the Inria, CEA, IRT SystemX, the Systematic cluster, Telecom ParisTech and Telecom SudParis. A concrete example of this scientific melting pot is the installation in 2016 of the Renault teams on the CEA - NANO INNOV premises in order to work on the development of the autonomous vehicle.

The Saclay data centers

The territory of the broadened plateau is characterized by a moderate density and a strong presence of open and agricultural spaces, a major issue in future developments. The solid electricity supply and the availability of source substations (notably that of Villejust[64] and that under construction in Saclay) are an additional asset for the future installations of data centers. Lastly, the proximity of research centers and activity parks like those of Courtabœuf and Vélizy are also favorable to the inclusion of data centers on this large territory. Seven data centers are currently being sited on the EPCI Paris Saclay territory. By broadening the scope, we were able to count 16 sites. Some of them propose hosting and are managed by major names in the field: DATA4 in Marcoussis since 2006, Telehouse in Magny-les-Hameaux since 2009, Colt in Les Ulis since 2016 and Atos in Clayes-sous-Bois since 2017. There are also more modest actors like Cloudata in Le Plessis-Robinson, Kheops/Fiducial in Vélizy and Alionis in Courtabœuf. In addition, there are many university and research data centers and those of companies and research centers like that of EDF Lab Paris-Saclay inaugurated in 2016.

On the occasion of the campus plan in 2010, several CNRS laboratories launched the Virtual Data project in order to build and pool two spaces intended for simulation and calculation (plateau room and valley room).[65] The first corresponds to the École Polytechnique data center. The second is a shared room that made it possible to bring together and rationalize the 650 m² of IT rooms divided among the different laboratories into a single 220 m² room. Water cooling was also installed. On its Bruyères-le-Châtel site, the CEA moreover has a super-calculator with power of 25 petaFLOPS per second (25 million billion operations per second), dedicated to research. This site is shared with other laboratories of the Saclay plateau.[66] In addition to these two uses (colocation and research), there is also the presence of large telephone operators onsite like SFR in Trappes and Bouygues Télécom in Montigny-le- Bretonneux. Their two data centers have a mixed function: hosting their own applications and services and hosting the servers of their corporate clients.

Unlike what was observed in Plaine Commune or Paris, we can take note of very recent installations with data centers like that of Colt built in 2016 and that of Atos in 2017. The attraction of data centers for this territory has been confirmed. According to the EPCI Paris-Saclay (cities organization), one of the GAFAM companies seems to be interested in opening a data center near Villejust.[67] For the moment, the discussion with the city seems to be leading to the use of an abandoned 15-hectaree plot, east of the A10 highway. This land has a large number of servitudes due to the electricity networks crossing it (two high-voltage lines and two medium-voltage lines). The land is registered as an national interest operation, and is located in a zone to be urbanized in the local urbanism plan. A feasibility study was carried out by Enedis (and paid for by the client) but the city does not have its conclusions. This study concerned the feasibility of three 15,000 m^2 buildings for total power of 60 MW, which could enable them to directly connect to the RTE lines as the power is higher than 50 MW.

According to Axelle Champagne, vice president for economic development and innovation at the EPCI, the Versailles-Saclay basin is solicited every other month for a search for land to build a data center. Two projects are moreover underway, related to the presence of DATA4, because each of these data centers will have a backup of its data at DATA4 in Marcoussis. We can see here how the concentration dynamic of data centers can function.

---

[64] The data base capareseau.fr indicates that the maximum additional power of this substation is 896 MW.

[65] Presentation de Virtual Data at the inauguration of the valley room, https://indico.lal.in2p3.fr/event/2311/contributions/4412/attachments/4192/5118/P2IO_Virtual_Data_-_Inauguration_Salle_Vallee_-_20140128.pdf

[66] Interview with Antoine du Souich and Mr. Simon-Pierre Kuzar of the EPAPS, April 25, 2018.

[67] Interview with Axelle Champagne, vice president of economic development and innovation of Saclay; Eric Siberath, deputy chief of staff in charge of digital strategy; Claire Le Strat, head of energy transition at the Paris-Saclay metropolitan community, March 2018.

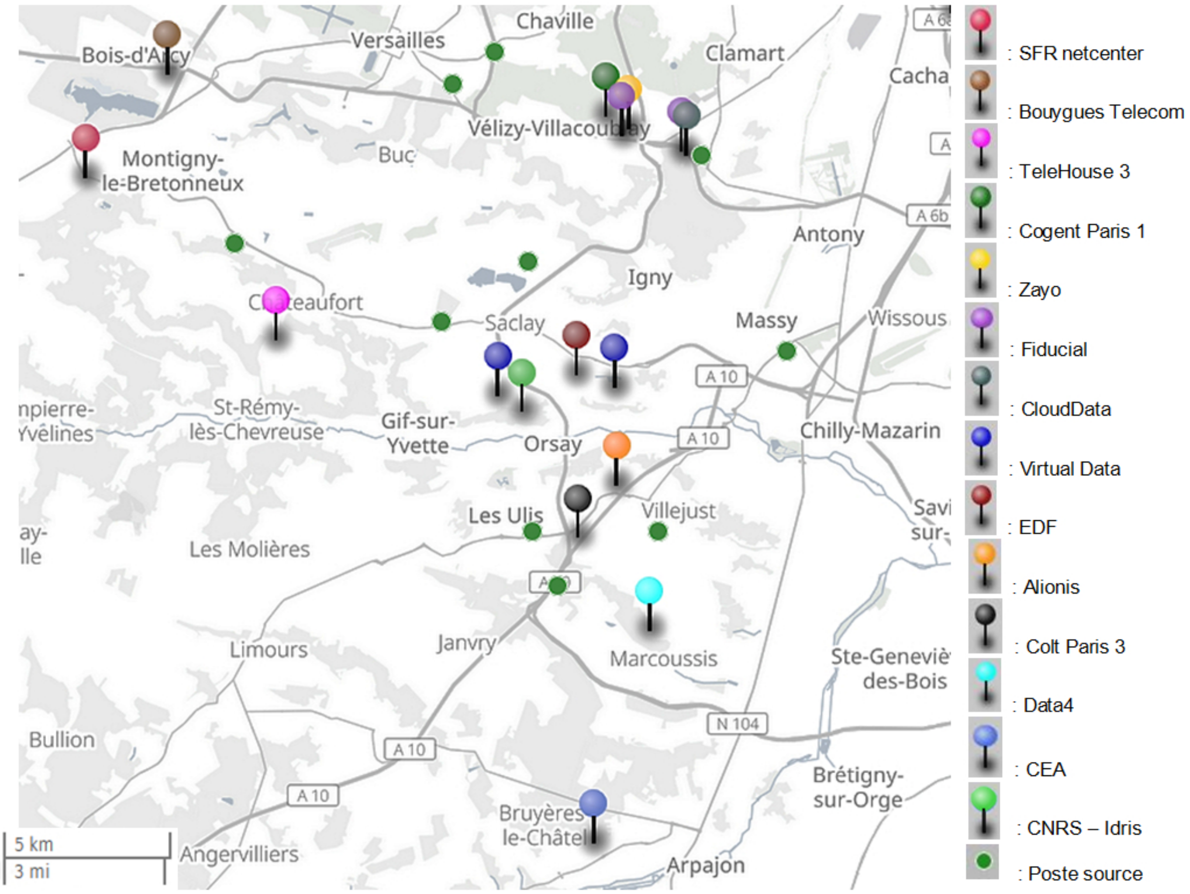


Figure 22. The data centers around the Saclay plateau, 2018. (background: OpenStreetMap, data: ENERNUM)

The calculation hypotheses to extrapolate the missing data of the table are provided in the annex. (Extrapolation/Sourced Values)

The data centers around the Saclay plateau, October 2018.

Company - data center	**Date of construction**	**Commune**	**Type**	**Size (m²)**			**Server power (MW)**	**Total available power (MW)**
				Plot	**Floor area**	**IT**		
GDC 2 - Cogent Communication	2006	Vélizy-Villacoublay	Housing + hosting			250		> 1 MW
GDC 3 - Zayo	2007	Vélizy-Villacoublay	Housing + hosting			2,000		Being renovated
Fiducial (former Kheops Organisation 2)		Vélizy-Villacoublay	Housing + hosting	1,230		230		>1 MW
Fiducial (for Kheops Organisation 1)		Plessis Robinson	Housing + hosting	6 hectares (activity zone)		650	1	3 MW
CloudData	2012	Plessis Robinson	Housing + hosting			1,200	2	6 MW
Atos - Bull 4 and 5	2017	Clayes-Sous-Bois	Housing + hosting	18,000		1,500	3	9 MW
SFR - Netcenter	2015	Trappes	Housing + hosting			1,000		12 MW
Bouygues Telecom	2009	Montigny-le-Bretonneux	Company + rental	18,000	9,882	3,660	6	20 MW
Telehouse 3	2009	Magny-Les-Hameaux	Housing + hosting	65,969	26,211	5,000	8.5	30 MW
EDF	2016	Palaiseau	Corporate R&D					-
Virtual Data (two rooms)	2014	Palaiseau	Laboratories 2 shared rooms			420	1.5	1.8 MW
Alionis DC 1	2005	ZA Courtaboeuf	Housing + hosting	5,000		1,100	2	6 MW
Colt Paris 3	2016	Les Ulis	Housing + hosting	30,572	13,161	5,000	8.5	20 MW
DATA4	2007	Marcoussis	Housing + hosting	111 hectares	39,000	1,000		100 MW
CEA		Bruyères-le-Chatel	Calculator			1,500		3 MW
CNRS - IDRIS		Orsay	Calculator					-
Total						40,510		**212.8 MW**

DATA4, a campus in the fields

DATA4 moved to Marcoussis in 2008, on the former Alcatel site, previously Laboratoires de Marcoussis of the CGE, the Compagnie Générale d'Électricité, which housed research on optical fiber. The footprint extends over 120 hectares, some of it wooded, and only one part is dedicated to data centers, while the rest is rented to other companies. It is the only data center campus in France that has large extension capacities. There is no electricity supply problem because it is directly connected to the RTE network, on the Villejust substation (inherited from Alcatel) and a transformer station was built on the site that has a 100 MW electricity capacity. The campus has eight data center buildings, and 20 are planned in the longer run. Today, through the purchase of a Guarantee of Origin (the European equivalents of the RECS, Renewable Energy Certificates), its energy supply is 100% renewable. Like Stockholm that created data center parks to gather together their installations, and force them to connect to the heating networks, the campus model can be interesting because of its capacity to bring together and pool infrastructures. But here, the typological choice favors a form of spreading, with new urbanism research that blends these data factories with homes scattered around the central pond. Siting on a territory like this which has a very low density also prevents any reuse of heat. The feasibility study underway will see if it is possible to inject this waste heat in the heat district system of Nozay, to heat agricultural greenhouses and public facilities.

Figure 23. DATA4 campus. Crédit=©DATA4 (left) Cécile Diguet and Fanny Lopez (right), 2018.

Around Saclay, as in rural Oregon, the dispersion of data centers has several repercussions:

- The invisibility of the phenomenon of digital installation accumulation and the energy weight of these infrastructures;
- Sprawl of farmland and non-urbanized land;
- The impossibility of energy solidarity between complementary uses, with the possible exception of agricultural greenhouses;
- A negative environmental and landscape impact (sealing of the ground, rupture of ecological continuities, anthropization, etc.);
- Balance of power that can be destabilized between Big Tech and small communities.

On the other hand, in peri-urban territories with abandoned or unused infrastructures, as is the case for the site focused on by one of the GAFAM companies along the A10 highway in Essonne, it seems interesting to target land restricted by servitudes or by the proximity of infrastructures that cause pollution or disturbances (though they can be rather unpleasant for the employees, even when their number is small).

3. The actors and governance of the digital territories

3.1 The ecosystem of data center actors

The world of data centers in France has brought together a large diversity of actors. We will cite the main ones here but not in an exhaustive manner.

- **The designers of data centers:**

  - **Land canvassers/real estate consultants**

CBRE, JLL, BNP Paribas Real Estate…

  - **Architecture agencies**

In France, there are three architecture agencies that specialize in data center projects:

- ENIA, which built the Orange and EDF data centers in Val-de-Reuil and BNP Paribas in Romainvilliers (which heats the nearby nautical center);
- The Emmanuel Kuhn agency, which works for example with Interxion (rue Rateau, La Courneuve; Europcopter site).
- RBA (Reid Brewin Architectes), which built for Equinix, for example (Pantin) and Global Switch (Clichy-la-Garenne).

Other architecture agencies designed data centers, but on a more modest or experimental scale:

- The GRAU agency, which built the data center of the Université de Bourgogne (300 m²), with a reinjection of the heat produced (400 kW) into the heating network of the city of Dijon;
- The architect Lina Gotmeh carried out studies for the data center project integrated into metro stations (described above) for the Société du Grand Paris.

  - **Engineering offices**

- Engineering offices specialized in critical facilities, with a global vision (cooling, energy, security, urbanization of data centers…);
- Engineering offices for energy and electricity, construction.

Global	Construction	Energy - electricity
APL Critical Building IBM Jerlaure	Cap Ingelec	Eaton Engie Axima Bouygues Energie et Service SOCOMEC Vertiv Engie Cofely

  - **Builders**
    - Bouygues construction
    - Vinci
    - Eiffage
    - Spie Batignolles

- SNEF

- **Equipment suppliers**: IT, electrical equipment, cooling systems… (and their after-sale services that intervene after the building is delivered)

IT	Electricity (inverters, switches...)	Energy (backup generators)	Cold – heating, ventilation, AC	Security	Equipment (racks, partitions, cable management)
Intel, HP, Cisco Google, Facebook, OVH	Schneider Electric Legrand Vertiv Siemens Eaton	Eurodiesel Caterpillar	Carrier Vertiv Stulz	Delta Security Solutions	Minkens Vertiv

The specificity of certain actors like Google, OVH and Facebook that manufacture their servers themselves should be noted. This enables them to control the whole production line and not depend on suppliers that can limit their insurance on equipment use, notably on temperatures not to be exceeded for good usage. This makes it possible to improve the PUE of the data centers.

- **The managers: upkeep, maintenance**

Actors present upstream for equipment supply:

- Vertiv
- Schneider Electric
- Delta Security Solutions

As well as general actors:

- Vinci Facilities, which includes data centers in its Facilities Management offering
- Engie Cofely (facilities management)

And specialized actors:

- Upkeep, cleaning: Cleansoft Solutions

- **The operators**

Apart from colocation operators, there is a large variety of actors for whom the data center is positioned at the center of their activities (non-exhaustive list):

- Digital services companies: Alterway Hosting, Agarik (Bull), Sopra Steria, Intrinsec, Atos.
- Hosting companies with added value: OVH, Aruba Cloud, Ikoula, Amen.
- The telecom operators: Celeste, TDF, Zayo, Acropolis Telecom, Orange, SFR, Iliad…
- Colocation operators: Equinix, Global Switch, Interxion.

For colocation operators, data centers are financial products with very high and very rapid profits (on average five years). Some large companies in the colocation sector like Digital Realty, CoreSite and Equinix are thus investment funds above all,[68] a status that in the United States makes it possible to considerably optimize taxation on their revenue (the REITs). They invest before building and standardize data centers on a global level. This positioning results in their not investing in projects or innovations with a longer-term amortization, like heat recovery, tri-generation or local renewable energy use projects for example.
If the colocation world (which only however represents 30% of data centers in France, according to GIMELEC) continues to strongly develop, a sizable consolidation has been underway for several years, toward a reduced number of actors consolidating enormous assets.

[68] REIT: real estate investment trust.

- The Cloud computing services: Microsoft, AWS, Google, OVH

It should be noted that Facebook has launched the Open Computing project to share its IT and technical strategy for the optimal performance of data centers.

3.2 The construction of expertise by local administrations

The world of data centers presents an opaqueness and a complexity that do not facilitate exchanges between the actors. However, when the data center was identified as an economic opportunity, as in Santa Clara (California) or Hillsboro (Oregon), the local administrations developed expertise and organized themselves in-house. We can note, on the other hand, that in France, notably in Saclay and in Plaine Commune, a dialogue seems more difficult to establish.

Santa Clara: autonomy, integration and anticipation

In the early 1990s, data centers, initially small ones, in the built environment, notably of telecoms, were installed in Santa Clara. Then, and particularly with the development of environmental labels and energy performance requirements, new ever-larger buildings were constructed. Whereas the city initially approved these projects without too many technical studies, especially focusing on water consumption for cooling (and the sizing of the sewer networks), it quickly decided to develop a one-stop service for the data centers and in this way proactively anticipate and organize the development of these digital infrastructures.[69]

This one-stop service brings together:

- Silicon Valley Power (SVP), the municipal electricity company created in 1896. One person is specifically in charge of data center clients (who represent 80% of the company's revenue). The company also developed and manages an optical fiber network (and free Wi-Fi in the city) and manages the water and sanitation networks.
- Firefighters: Santa Clara is one of the rare cities in Silicon Valley that does not have firefighters attached to the county, but a municipal corps. According to the city, this makes it possible to find consensual solutions more easily with the data centers, more in terms of an obligation of results than of means.
- The urban planning and environment departments.

Technical project reviews are conducted in three or four weeks, after which the permits are granted or rejected. All the partners, in particular SVP, are involved in the projects as much upstream as possible, to better very quickly take the technical constraints into account.
The city of Santa Clara consequently reuses the profits generated by Silicon Valley Power in the city's public facilities. One example is the imposing football stadium built in the northern part of the city, but more generally the quality of the public spaces, parks and local facilities. We may note here the interest in the municipalization of certain services for an integrated and connected approach to the siting of complex facilities, namely data centers, but also to relocate the economic benefits.

Hillsboro, a partner-based and economic strategy working group

Like Santa Clara, the city of Hillsboro, in the Portland suburbs, quickly identified the data center sector as an economic segment to attract to consolidate its positioning in the digital sector, and moreover being a better and less risky alternative market than California (earthquakes, drought). The city, through its economic development department, has furthermore been very offensive, in many international trade shows, to vaunt the merits of its territory in terms of connectivity, land and the economic environment.[70]

---

[69] Interview with Yen Chen, head of urban planning for the city of Santa Clara, op. cit.
[70] Interview with Mark Clemons, economic development director of the city of Hillsboro (now retired), September 19, 2017.

The technical departments of Hillsboro therefore play a role of mediator and facilitate all the installation, development, contact and coordination steps with the electricity company, the network, the state of Oregon and Portland Metro for the installation of data centers, whether they are colocation or dedicated to companies. The city has also created a dedicated working group with the data center operators in order to more generally exchange information on the projects on the construction of source substations by PGE (Portland General Electric), on relations with the Portland metropolitan area and tax questions with the state of Oregon.

Paris Saclay, energy as an entry point

The particularity of the Paris Saclay territory is that it has governance on several levels with the EPCI Paris Saclay on one hand, and, on the other, the Établissement public Paris Saclay, the state operator that covers the territory of the Operation of National Interest (OIN).
As for the EPCI (cities organization), a relative expertise was built because DATA4 has been present on the territory, in Marcoussis, for a decade. Moreover, through the Climate and Energy Plan expertise, the metropolitan area is aware of this issue and would like to be able to include the data centers in the local energy strategy. However, there is still no exchange venue or working group on the subject. It would seem that the projects are only being currently treated on a case-by-case basis. However the EPCI has recently acquired the competence of an energy distribution organizing authority (AODE) and will therefore become the authority that organizes electricity distribution for 13 of the territory's 27 communes (the others are part of the Intercommunal Gas and Electricity Syndicate in Île-de-France [CIGEF]). Moreover, the Climate and Energy Plan is underway for 2018-2022, with a prospective vision for 2030-2050 in which the digital infrastructure question can be taken into account.
Today, here too, only Enedis has a global view of the real electricity consumptions of data centers and pending projects, a view that would permit crossed planning between energy and urbanism if it were shared. Enedis however stresses that these data are confidential since they concern its clients. It must also be noted that the data center operators do not transmit these data because on one hand, they could show to what point the power requested from Enedis is higher than their real consumption and, on the other, their electricity consumption could give their competitors an idea of their filling rate, which is not always high, and therefore of their economic health.

A research and development project initiated by IRT Systemic, notably including the EPCI, RTE, EDF, Enedis, GRDF and Dalkia, aims at building a digital modeling platform to better understand the territory's energy consumptions, and making projections. This project however has just begun. It could constitute an advance for the EPCI, a new tool for energy and territorial steering and planning, but it is still too early to say. Consequently, the EPCI seems to be advancing more broadly on an energy planning and strategy in which the data centers could be included. Moreover, as the proximity of optical fiber (near the highways) and source substations (far from residential areas), are favored siting factors for data centers, the question of their location on abandoned infrastructural spaces inappropriate for other uses also seems to represent, for the EPCI, an opportunity for the digital planning of these interstitial areas.

As for the Établissement public d'aménagement Paris Saclay, the angle of attack for the data center question was first that of incorporating their waste heat into the urban heating network on the Saclay Plateau, the question of urban or architectural integration not being raised because data centers are inserted in schools, research centers and companies. In the first phase of the urban heating network, using this waste heat is not relevant because there is enough renewable energy with geothermal energy. The question must be asked again later. It should be noted that like the autarkic functioning on the academic level of certain prestigious schools or research centers, the time has not yet come to examine the question of pooling the digital or energy infrastructures linked to data centers.

3.3 Local administrations faced with opaqueness

Prineville, Umatilla, Boardman: an unequal contest?

If data centers often replace aluminum foundries and sawmills, which needed a large amount of electrical power, the power used by data centers is often higher and the potential imbalances on territories greater.
The secrecy that surrounds the siting of data centers as can be seen for Prineville, but also more generally for a great many territories, is closer to that which usually concerns military or government intelligence sites. How can the development and planning of its territory be mastered under these conditions?
This imbalance in information does not permit local administrations to sufficiently anticipate a position on the data center question, to consolidate expertise on the subject, on the alternatives for urban, architectural and energy integration siting, for example.
This is all the truer in rural territories like Prineville and Umatilla, where the technical departments are not necessarily equipped for these subjects, where the political or demographic weight of the territories is not of the kind to offset the power of Big Tech in particular and, finally, where the often difficult employment situation leads to favoring the creation of jobs over long-term urban, energy, environmental and economic questions

Plaine Commune, a rapid and uncoordinated development

On the Plaine Commune territory, north of Paris, the first data center arrived in 1999 (Interxion), then, in a decade or so, the territory became a major digital hub for data centers. This new corporate real estate, more or less unknown until this point in time, consequently developed on the Saint-Denis plain, and notably in La Courneuve.
The subject only become strategic and raised questions starting with the publication of the ALEC study in 2013, whereas numerous data centers had already been built. However, in the absence of a strong political support of the subject, an alliance between the communes concerned and the metropolitan area, the construction of an expertise on data centers, there was no authority or strategy on the issue. The conclusions of the ALEC study therefore had not been followed by actions, notably on heat recovery.
Most of the installations have received an ICPE authorization delivered by the government, but this has not constituted a lever for genuine negotiations. Moreover, only Enedis (but neither the communes nor the metropolitan area) has a view of the real electricity consumption of the data centers, and of backup power or power on a waiting list. This constitutes here, as in the broadened Paris Saclay territory moreover, a major difficulty in terms of treating the projects and the urban planning authorizations, with a global view.

The case of Eurocopter, discussed above, lastly illustrates the difficulty for the metropolitan area and the commune to work in partnership with a dominant actor of the market, and to consequently attempt to reconcile economic and digital development with a need for building housing and the search for greater urbanity for a district with deteriorated public spaces that are not pedestrian-friendly and which however are numerous.

3.4 Energy and telecom operators: dependencies and disruptions

The American energy market and the history of its deregulation vary from one state to another and present major differences with the French situation. We may however note that on both sides of the Atlantic there are common characteristics as to energy transition imperatives and the resistance of the utilities that see their markets turned upside down and their activities radically transformed. In the United States, in a general manner, the condition of the electricity distribution networks is of lesser quality than in France where the RTE and Enedis monopoly have made possible very heavy investments in infrastructure.

In the three American areas chosen, the energy territories are certainly specific but the production of a large quantity of renewable energy is a constant.

- In California and in Silicon Valley where despite the high price of electricity (excepting Santa Clara), there are many data centers, they take part in the development of renewable energies (RE represents 27% of State electricity production).
- In Oregon, the weather is cooler and electricity less expensive thanks to the hydraulic dams on the Columbia River. 71% of Oregon's electricity production is generated by traditional hydroelectric plants and other renewable energy resources.
- In the state of New York, it is New York City that has retained our attention for its urban density and the gradual transformation of emblematic telecom buildings into data centers, in a post-Hurricane Sandy context that has favored very strong energy resilience policies, notably in terms of renewable energy and micro-networks (23% of electricity production in the state of New York is renewable).

The digital attacking the old utilities

An immense quantity of energy consumed
In the United States, in 2014, data centers consumed about 70 TWh, which represented 1.8% of the country's total electricity consumption. Their consumption had increased by 4% between 2010 and 2014.[71] In California and Oregon, data centers are perfect clients for the electricity companies: no peak to manage, a large stable consumption day and night, all year long (flat loads), and growing. Whereas energy efficiency programs are beginning to bear fruit, household consumption is decreasing and it is difficult to finance new electricity production and transmission infrastructures, the digital is a windfall that is calculated in megawatts (and therefore in dollars) for the old American utilities that are facing increasing competition, notably in terms of the production supply. In Prineville with the arrival of Facebook and Apple storage infrastructures, energy consumption soared from 10 MW to 500 MW.
In France, in 2015, data centers consumed between 9 and 10% of electricity or 3 TWh. The cities of Saint-Denis and Aubervilliers, on the Plaine Commune, with respectively five and eight data centers inventoried, had total available power of about 150 MW. For the most part, these are large data centers with high energy consumption, that can be as much as 64 MW for the future data center of the operator Interxion in La Courneuve.

Big Tech are exerting pressure on the historic electricity companies
For Gary Cook of Greenpeace, author of the report *Click Clean*,[72] if the GAFAM companies are making an effort on renewable energy, notably by displaying commitments to be supplied by 100% renewable energies, there is still a long way to go because this energy is not local, nor additional, or really used by their data centers: it is partially purchased from the electricity companies through certificates (REC in the United States and GO in Europe). GAFAM are increasingly demanding and go as far as forcing the energy transition of certain old utilities with a high-carbon mix… This is notably the case in certain American states where land is very inexpensive and the energy mix contains a lot of fossil fuel (with coal-fired power plants whose industrial lobby remains powerful). In Wyoming, Microsoft had negotiated an agreement with Dominion Virginia Power and the state government to demand the production of a 20 MW solar-powered plant. The company has done the same in Europe where it has just signed a contract to reserve the entire electricity production of a General Electric wind farm, very recently started up in Kerry county in southwestern Ireland. This purchase aims at greening the energy mix of its large data center west of Dublin dedicated to Cloud services for all its European corporate clientele. In contrast, the latest report (2019) Clicking Clean specifically targets the cloud leader, Amazon Web Services, whose new data centres built in the Ashburn cluster near Wahsington DC are all coal-fired. The author points out that the exceptional growth of data centres on this vast site justifies, for Dominion,

---

[71] Shehabi Arman, Josephine Sarah, Sartor Dale A, Brown Richard E, Herrlin Magnus, G Koomey Jonathan, Masanet Eric R, Nathaniel Horner, Inês Lima Azevedo, William Lintner, 2016, op. cit.

[72] http://www.greenpeace.org/usa/global-warming/click-clean/

the local electricity company, supporting the development of the Atlantic Coast pipeline (ACP), whose environmental effects are considered devastating on the Appalachian mountains and CO2 emissions and pollution. Few weeks after that, and Dominion Intergrated Resource Plan refusal by the State, WAS was signing a letter with other digital companies, to push Dominion toward a greener energy mix.

New renewable energy producers

On the West Coast, Big Tech seem to exert strong pressure on the energy system to turn toward the use of renewable energy, and would like to put an end to the monopolies of the electricity companies that seem to be blocking them from reaching this objective, the energy companies wanting to first make their current installations profitable before investing in new, cleaner ones. Apple therefore created its Apple Energy subsidiary that enables it to sell the surplus energy produced by four of its American installations, including the Newark wind park in California. These renewable energy productions (solar, hydraulic, wind and fuel cells using biogas) enable the company to flaunt: “100% renewable energy for 100% of these installations,”[73] notably for its data centers. In Oregon, Apple purchased the 45-Mile hydroelectric dam to supply its Prineville data center. Certain GAFAM companies also increasingly envisage developing their energy autonomy and their own production infrastructures onsite or nearby.

Autonomy aspirations

In France, the weak presence of GAFAM limits a form of competition on the electricity moreover locked up by the Enedis monopoly for distribution. However, the capital resources of the major colocation data center operators enable them to invest in the construction of electricity infrastructures and dark fiber networks. In a certain way, they then replace the historic electricity distribution and telecom operators.

The construction of source substations or high voltage at the source

Large data centers follow the geography of transmitter stations and have a large quantity of backup electricity. In France, for distribution, they have three options. The first is to locate near existing transformer stations. The second is to ask Enedis to build new ones. The third is to build them themselves. In the Île-de-France (Greater Paris), for Enedis, the known data center projects correspond to a doubling of the network capacity of the north of Paris over the next five years. For data center industrialists, there are major issues on distribution (that is, the moment when the voltage level drops from 250,000 V to 20,000 V). Access to a source substation is a major element of the business model of these industrialists. Historically, the duration of the construction of a source substation by Enedis was five to seven years. The data center industry is trying to exert pressure to lower it to three years and sometimes does not hesitate to circumvent Enedis to turn directly to RTE, when the power of the buildings exceeds 40 MW (the regulatory threshold starting from which this is possible). They will thus directly connect to a RTE high-voltage line. This is therefore a new location criterion. This is notably the case of Interxion. Consequently, Fabrice Coquio, president of the France group of Interxion, asserts: “We already started in Frankfurt where we built a source substation of 100 MW and are in the process of building one in Stockholm. I will be filing a permit soon in Marseille because I grabbed everything that remained: 90 MW, there isn’t anything left . […] You have to be a real expert in energy management and infrastructure management to know how to operate a source substation and you have to have the means. For 73 MW in Frankfurt, it was 25 million euros. That immediately clears the ranks of who can do what.”[74]

Furthermore, data centers must now pay 100% of the connection to the source substation whereas in the past it was Enedis that took this cost in charge.

The situation is the same in the United States. The Sabey data center heavily invested in on-site infrastructure with the construction of four electricity substations ($25 million), which ensures it a lower energy price over the long term (currently 14 cents the kW/h[75]). For its New York site, Sabey uses an ESCO[76] to buy energy – Constellation Energy – and only pays Con Ed for the distribution. The maximum

[73] https://www.apple.com/fr/environment/climate-change/
[74] Interview with Fabrice Coquio, president of Interxion France group, March 6, 2018.
[75] As against, for example 22 cents the kW/h by 365 data centers, also located in Manhattan (interview with Jim Grady, January 2018).
[76] ESCO: Energy service company.

available power is 40 MW, but only 18 MW are currently consumed. The company has not positioned itself on renewable energies.

Telecom infrastructure: PoP and dark fiber
Actors like Interxion and Equinix also create their own telecom infrastructures to replace operators that no longer have, according the them, the money to build them. “When you’re a telecom operator, to make a hole in the sidewalk to connect to a data center, its €1,000 a meter. Next, to install a PoP (point of presence), an active telecom element to deliver services, it’s an investment of between €500,000 and €1,700,000. Given that prices are dropping by 30% a year, you wonder how many meters you have to do. If you have 30 km of networks to create, which however on a country-wide scale is nothing, you don’t do it.”[77] Consequently, Interxion builds considerable capacities (832 pairs of fiber) that are sold to SFR, Orange, etc. There is a substitution interplay that is created between the historic operators and the data center operators that without having infrastructure licenses can install them since it concerns linking buildings that belong to the same data center operator.

The organization of the territory and the disrupted network

Energy appropriation beyond real needs
For Brigitte Loubet, special heat advisor of the DRIEE, as for Fabienne Dupuy, deputy territorial director for Enedis in Seine-Saint-Denis, data center requests can be blocking for the territories. Electricity control can be summed up as: first there/first served, waiting lines are constituted on different sites. Backup power (60 MW for five years, 10 years) is blocking for other clients whereas this power corresponds to a maximalist consumption hypothesis (when the data center is full, which sometimes takes several years). The ALEC study already questioned this subject in 2013. Marseille is an example, where the mayor Jean-Claude Gaudin had to negotiate with Interxion to recover 7 MW “because they had forgotten to reserve it for their electric buses.”[78]
André Rouyer, digital infrastructure delegate at GIMELEC, has drawn attention to the risk of excess and mentions that the colocation market disturbs readability and calculations and participates in this mystification: colocation data centers are filled on average at 30-40%, some less than 20% and colocation is 30% of the market. “Data centers were built but what happens in these professions is a little like a headlong rush. They say they want to build a data center because they want clients, therefore if there aren’t any spaces there aren’t any clients. If you to go to Saint-Denis and visit the colocation data centers, they are very far from being full. They operate but when you see the charges, they all need clients.”[79]
The developer and the local administration harnessed
The territories are all the more disturbed because they must now participate in the investment in electricity infrastructures. The law on solidarity and urban renewal (SRU law) modified investment conditions for electricity infrastructures, for all electricity transmission. The developer and the local administration must financially participate, whereas before EDF made a great effort to structure its network and strengthen it.

Ever stronger requirements from the public authorities?
How can data centers be encouraged to play more as a team? Could the local administration, Enedis, even RTE in the name of the general interest force them and impose installation sites as is the case in the city of Stockholm? The Stockholm Data Parks Initiative obliges the data centers to be installed on campuses where the heat generated must be reused. This program was launched in partnership with the urban cooling and heating operator Exergi, the electricity operator Ellevio and that of dark fiber Stokab. This experimentation and the city of Stockholm’s involvement seem relatively unique to us.

As David Rinard, sustainable development director of Equinix[80] recalls, whether it is in the United States or France, any gain in energy efficiency and any new capacity in captured renewable energy makes it possible above all to consume more, and at a more stable price. This is the rebound effect, also called the Jevons paradox. As technological improvements increase the efficiency with which a resource is used, the total consumption of this resource can increase instead of decreasing. In other words, the use

[77] Interview with Fabrice Coquio *(*idem).
[78] Idem.
[79] Interview with André Rouyer, digital infrastructure delegate, GIMELEC, op. cit.
[80] Interview in San Jose, October 9, 2017.

of more efficient technologies in energy that emit less CO_2 does not guarantee a drop in total energy consumption, quite the contrary. The data center industry is a good illustration of this paradox.

3.5 Collective governance: structures to move toward a better integration of data centers

In the United States, traditional lobbies and energy-related structures

Colocation data centers have prudently taken part in the energy transition dynamic, by finding a balance between a low-cost energy and the wish to green their image. Their clients are varied and numerous, and do not exert strong pressure to turn more toward renewable energies. On the other hand, the majors of the digital are often much more demanding for their own data centers, but also for those that host the metropolitan locations of their Clouds: colocation data centers.
Some like Facebook, Autodesk and Salesforce are brought together in organizations like BSR™ (Business Social Responsibility), through its program The Future of Internet Power" to exert pressure on colocation data centers to move toward more renewable energies and transparencies.[81]

Others belong to REBA, the Renewable Energy Buyers Alliance, a federation of renewable energy buyers that work on rates and offerings, in liaison with energy actors. The best known, Google, Facebook and Microsoft, negotiate directly with electricity companies where they are sited to obtain the desired energy mix, and honor their commitments on renewable energies. Google consequently announced in late 2017 that it had succeed in consuming 100% renewable energy over the year.

The 7×24 Exchange was founded in 1989 to institute a dialogue between IT actors and those of data centers. It brings together today the data center actors (designers, builders, managers…) to discuss common issues but also to take up questions on social and environmental themes. A conference is held every year on often very technical themes. The energy impact of the digital is not the main focus of its action.[82]

Lastly, more locally, the Silicon Valley Leadership Group, created in 1977 by Silicon Valley entrepreneurs for the territory's economic vitality and quality of life, initially had three objectives:
- Reducing traffic congestion;
- Improving housing opportunities;
- Promoting an energy strategy (first from the air pollution angle).

It now has eight work tracks and 365 member companies, including GAFAM and data center operators. The association has publicly positioned itself on a 100% renewable energy supply and agreement with the objectives of the COP21 of Paris.

As for the Energie working group, it has three work tracks for 2018-2020:
- Supplying clean energy;
- Modernizing and making reliable the gas and electricity network; developing distributed energies;
- Finding solutions for the demand side: energy efficiency, load management.

In France, electricity and digital lobbies

In France, three entities represent the interests of data centers:
- France Data Center;
- The GIMELEC;
- The AGIT.

[81] Interview with Michael Rohwer, BSR, October 2017.
[82] Interview with David Schirmacher, president of 7x24 Exchange, New York City, January 2018.

The goal of France Data Center, which succeeded the CESIT (Club des Exploitants de salles informatiques et télécom) in 2016, is to bring together all the actors, to act in a concerted fashion with the GIMELEC and the AGIT, and to defend the interests of data centers. It has over a hundred data center operators. After having especially been an organization focused on the sector's internal performance, the dissemination of good practices, FDC also wishes to further increase the value of data centers as a strategic digital infrastructure, improve their image and act as a lobby, notably on energy and tax questions.

The GIMELEC, a group of electrical equipment industries and control command systems and related services, is an employers' organization. One of its working groups focuses on digital infrastructures, a secure electrical power supply and energy performance. In this framework the GIMELEC is currently participating in work on the European Code of Conduct for data centers. André Rouyer, who steers this working group, stresses that is it urgent to recognize the importance of data centers in general digital functioning, to consider them a strategic infrastructure.

The AGIT, Alliance Green IT, promotes green for IT, in other words, a digital sector with a lighter environmental impact (energy performance, eco-design of software, recycling…). It published in 2015 and 2017 a green IT practices barometer, one of whose sections concerns data centers. It moreover organizes events, training sessions and contributes to publications on the subject such as the ENR'CERT study on the energy efficiency of data centers, mentioned above.

There are no associations or structures in France that bring together energy specialists, local administrations and data center operators whether they are local or national.

Several points seem central to guarantee better understanding between the actors and to envisage less sector-based approaches. However, a certain number of curbs block not only comprehension today but more generally the possibility of pooling or working on a common project between colocation operators and local administrations.

- The opaqueness and lack of information does not make it possible to anticipate or plan for better coordination of a territorial project whether it is urban or concerns energy.
- The question of the convergence of the actors' interest is raised. The financial profitability of a real-estate operation for operators like Equinix or Interxion eludes the very idea of general interest supported by the administrations.

4. Data centers, a new piece of the energy puzzle

4.1 New infrastructural backups

Data centers are machine-buildings that contain backup systems and an impressive infrastructural redundancy. In order not be weakened by possible electricity cutoffs that could affect the system and impact storage, data centers have two current supplies and backup systems (generators and batteries) that make possible service continuity in "autonomous" mode for at least 24 hours, but more often 48 or 72 hours. These security backups are exceptionally mobilized, on average once every five years for very short durations, from a few minutes to a few hours depending on the territory.

If the risk of disasters varies according to the region, all the data centers pay a great deal of attention to guaranteeing their clients energy autonomy in the event of problems, which is a primary sales argument. Cutoffs that last several hours remain exceptional, for example when Hurricane Sandy struck. One third of New York's population found itself in a blackout and 50% of all the data centers were out of order; backup systems were able to provide service continuity in certain cases.

This infrastructural equipment heavily impacts spatial organization since the IT storage rooms are doubled by infrastructural backup areas adjoining the rooms, on the same level, but sometimes in the basement, on higher floors or on the roofs.

- **111 Eighth Avenue, 32 Avenue of Americas and 60 Hudson Street**

The roofs of these buildings are dizzying outgrowths, including backup diesel generation, water cooling towers for air-conditioning, satellite disks of all sizes and shape, water tanks in the event of a cutoff, cranes to mount the diesel generators from the street, etc. Their basements are loaded with cables, equipped with fuel oil tanks that hold several hundred thousand liters to supply the generators in the event of a shutdown of Con Edison's electricity network, as the utility supplies most of the city.

111 Eighth Avenue is the former headquarters of the port authority. The fourth largest building in New York in terms of floor area, bought in 2010 by Google for $1.9 billion, it is notably its infrastructural specificities that attracted the interest of the Web giant.

- Fuel reserves of 600,000 liters ensure resilience in the event of an electricity cutoff. Google and its service manager Taconic carried out a feasibility study for a gas-fired cogeneration plant, but have still not selected this option. They are now studying the possibility of recycling the organic waste produced in the building to turn it into energy and to use biogas or methane as a primary energy to replace fuel oil generators.
- Thermal storage: water is cooled at night in tanks when electricity is inexpensive and restituted during the day to air-condition the data centers.

Figure 24. Roof of 111 Eighth Avenue. Credit =©Cécile Diguet and Fanny Lopez, 2018.

Figure 25. Interior of 111 Eighth Avenue. With fuel tank and thermal storage. Credit =©Cécile Diguet and Fanny Lopez, 2018.

- **The Sabey data center** presents similar features. The building has reserves of a million liters of water on the ground floor, and gasoline storage of 700,000 liters (a full load autonomy of 72 hours).

This infrastructural redundancy first raises the question of the optimization of resources and systems onsite. For example, instead of the thousands of liters of fuel storage for the backup generators, the gas or biogas-fired cogeneration or trigeneration plant increasingly seems to be an alternative backup system and could be a less polluting and less risky option. This is notably the case for the New York Times building in New York City whose data center has a gas-fired cogeneration plant as its backup system. This is also the case for the Citibank data center in London. There are other examples of this type in Europe. In France, GDRF is making a great effort to develop this market but the data center operators remain conservative and reticent about changing a system that they know perfectly. It is also political support for this source that is lacking as Guillaume Planchot of the IDEX energy company stresses: “Today, CHP in France, with perhaps self-consumption, would be extremely relevant vis-à-vis data centers, even perhaps trigeneration. We had as much as 5,000 MW of cogeneration (CHP) installed in France whose heyday was probably 2005-2007. This is all the same equal to five nuclear units. But I believe that over 3,000 of them have been dismantled since there are no longer feed-in tariffs, they’ve very much deteriorated, the sector hasn’t been supported.”[83] Fuel cells are also an alternative and certain GAFAM companies have equipped themselves with them.

This infrastructural redundancy is also a track for pooling, which perhaps would make it possible to offset the impact of their electricity consumption, but exchanges with the territory and technical and financial balance remain complex to find. The difficulty in recovering heat is witness to this phenomenon.

4.2 Difficult heat recovery

In 2012, in the preparatory work for the Paris Region air, climate and energy plan (SRCAE), the DRIEE (State administration) had identified the major challenges linked to recovering heat from the data centers whose average temperature is around 40-50°C, a resource called “Low Temperature” (<60°C). The ALEC had formulated a recommendation to go deeper into this subject that was partially concretized with the ADEME study on waste heat.[84]
In this study, the authors estimated that the total maximum accumulation of waste heat in the data centers in the Île-de-France amounted to 490 GWh (concentrated on Aubervilliers) out of the 26,500 GWh analyzed.[85] However, this estimate should be considered with caution because it was made solely from information transmitted by the data center operators who wished to answer the questionnaire.

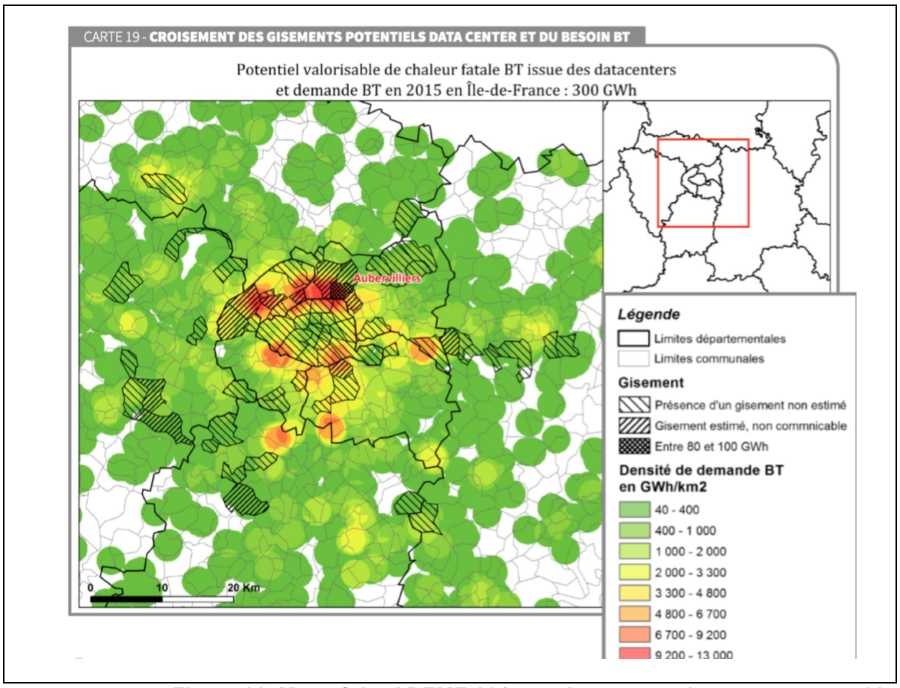


Figure 26. Map of the ADEME 2017 study on waste heat recovery, p. 39.

[83] Interview with Guillaume Planchot, heat and cold network development director IDEX, March 20, 2018.
[84] http://www.ademe.fr/etude-potentiels-production-valorisation-chaleur-fatale-ile-france
[85] Ibid. p. 23. “The maximum accumulation of waste heat in the Île-de-France, for the perimeters of wastewater, industrial waste heat, waste incinerators and data centers is estimated at 26,500 GWh, or 22% of the fuel demand of the region’s residential, service and industrial sectors.”

Multiple potentialities but a blocking operational reality for heat networks

The incorporation of heat in the urban heating networks interests managers of the CPCU (Compagnie Parisienne de Chaleur Urbaine) because this does not mobilize their capital investment expenses; the implementation however is difficult. Among the technical curbs, the study stresses the "lack of durability of the resource," that is that the increase in performance could generate a decrease in the waste heat emitted. Regarding the interviews we conducted, two parameters seem blocking and explain that the recovery of waste heat from data centers has remained at a standstill.

- Economic curb: economic profitability models and interests diverge. For the data center developers, an investment in a heating network project is not interesting in terms of economic profitability. The world of real-estate development of colocation data centers incurs ROI over very short periods from two to five years for clients who are often outside the territory potentially served by the heating network being studied. For heating networks, contracts require commitments over durations of 25-30 even 50 years. The project timeframes do not correspond to these durations.

- Technical curb: it is preferable to envisage heat recover when the data center is being built because intervention and work on the existing structure can disturb its operation. The cost of the existing systems to be changed is also a factor and technical adjustments can be a major obstacle. The opportunity for a new construction or renovation seems more relevant, even if the connectable distance and required temperature must be carefully studied (the heat networks in the Île-de-France generally have temperatures of between 60 and 110°C). For connection to new buildings, it is also indispensable to evaluate the relevance of such a connection and the related costs because with the RT 2012 standards[86] (and the ones to come), temperature needs are lower. It should moreover be noted that the world of data centers is involved in a drastic reduction to control energy internally on the scale of the building (major investments of software efficiency, hardware, free cooling, etc.). These electricity consumption reduction methods (notably by free cooling) also prevent a maximum of energy from being recovered.[87] There is a competitive dimension in this choice as the new data center market is attempting to reach the lowest PUE possible.

Many studies conducted did not go any further:

- An opportunity study was conducted in Courbevoie in 2016 in the framework of the Village Delage urban project to study the possibilities of recycling existing thermal resources. This study only focused on the single data center that was going to be relocated during the district's restructuring. As the future of the two other data centers, notably that of SFR with its 10,000 m² of hosting was not known, heat recovery was not studied. The conclusion of this study was "that it is practically impossible to forecast what a data center will be 10 years from now" and that heat recovery could not be envisaged for Courbevoie, which has however an urban heating network.

- Feasibility and technical studies were carried out in Clichy on the Global Switch data center. The data center and IDEX, which manages the heating network of the cities of Clichy and Levallois, did not succeed in agreeing on contractualization whereas the technical studies showed that the technical and economic conditions were present.

- The architect of the Interxion data center in La Courneuve, on the rue Rateau, mentioned the existence of feasibility studies conducted during the building's design. They were not taken into account.

---

[86] Energy regulations for buildings

[87] Feltin Gabrielle, Boutherin Bernard, Canehan Xavier, 2017, "Indicateurs pour un *datacenter* efficient ? Mesurer pour améliorer !," JRES.

Studies underway:

- **Chapelle International**
A study is underway for the future “Chapelle International” district, which will be delivered in 2021. It was announced that this new district will have the first autonomous heating loop in Paris, steered by the CPCU (Compagnie parisienne de chauffage urbain), which will supply energy for Chapelle International from a boiler built at the south end of the logistics building. The future data center of the city of Paris that will be installed in the logistics hall, next to the future boiler room, will be connected to the heating network. With 50% renewable energies, all the site’s buildings will be supplied with hot water (in a closed circuit). The boiler room’s operation will be ensured by a biogas plant.

- **The Saclay heating network: uncertainty on the integration of the data center**
Today, the connection of the data center to the urban heating and cooling network is still not in the operational stage. The first reason is that the infrastructure of this network is complex, and has not been completed. Efforts are therefore initially being focused on the network “alone”. Next, the network will be built up as new buildings are constructed on the plateau. In the first phase, the network as it was designed today meets the energy performance objectives set (>50% of renewable energy and recovery, <100 g of CO_2 per kWh produced). Nevertheless, in the medium term, the network’s energy mix will include recovered energies.
The last constraint is that a legal framework remains to be established for the purchase of energy by a third party, as well as related rates. A detailed study phase is underway for a connection of the heating network to IDRIS, the super-calculator of the CNRS already installed onsite. The objective at this stage is a connection within three years.

Local loops more easily installed

Heat recovery for offices, housing and logistics spaces in the immediate vicinity is a more common scale of reuse:

- In Bailly-Romainvilliers in Marne-la-Vallée, in the Le Prieuré commercial economic zone, the heat recovered from the 10,000 m^2 of the Natixis bank’s data center makes it possible to heat and supply domestic hot water to an aquatic center and a business incubator of 1,800 m^2.

- This is also the case for Céleste, an Internet service provider and operator of a national optical fiber network, which, in 2012, had its data center built by the Enia architecture office, in Noisy-Champs (77). The architectural design makes it possible to cool this high-density data center without having to produce ice-cold water. 95% of the year, it is the use of ambient air – free cooling – that cools it. The heat emitted by the machines is used to heat the offices.

- Another example of heat recovery is Iliad, at the former site of the central laboratory of the Ponts et Chaussées engineering school in the 15th arrondissement of Paris. Illiad installed a data center in a former bomb shelter abandoned since 1991. The heat produced by this ultra-secure data center, dedicated to archiving, will be recovered to heat low-income housing, built above the bomb shelter. This partnership with Paris Habitat, which will last 10 years, will make it possible to recover 250 kW in winter for heating and 700 kW for domestic hot water production. For the inhabitants, this will represent a savings of €500 on their yearly charges.

- The data center of the Université de Bourgogne is used to heat the adjacent building via the university’s heating network. This has been made possible because the boiler room supplying the university’s heating network is located in a building adjacent to the data center. 5% of the school’s heating needs are consequently recovered, amounting to 400 kW.

Another way of using the heat emitted by the computing or storage functions is to “separate the data center into pieces” and move these elements. This is the principle of the digital boiler system or Qarnot heating: the data center is broken into pieces and, brought as close as possible to the heating needs, makes it possible to save on the network part.

- **Stimergy: the digital boiler**
  The Butte-aux-Cailles swimming pool (Paris 13th arrondissement) is heated at 30% by six digital boilers (computer servers) made by the Grenoble company Stimergy.
  The six boilers installed have made it possible to save on the heating bill and the carbon footprint since 50 tons of CO_2 are saved a year. These boilers have also been installed in buildings and eco-districts in Nantes and Grenoble in low-income and student housing, with savings of 40% on the heating bill. The servers are placed in an oil bath that absorbs the heat produced and heats the hot-water tank. Thanks to water heated to between 45 and 50°C, the digital boiler makes it possible to cover 30 to 60% of the building's needs

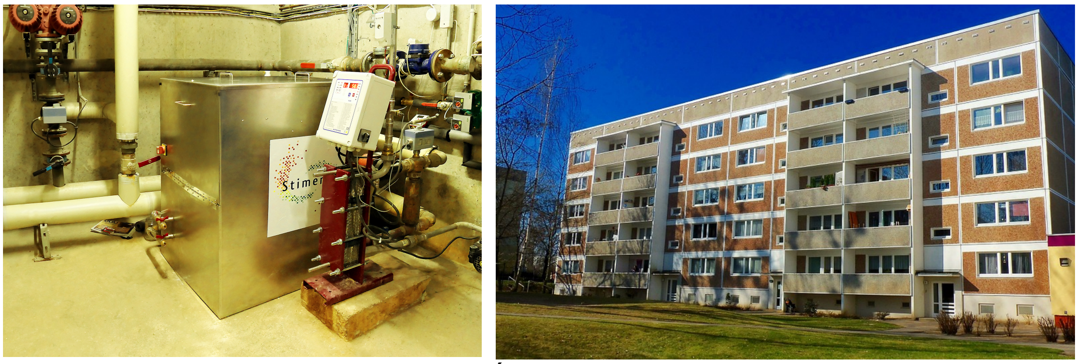


Figure 27. Stimergy digital boiler installed in a building in Échirolles with the OPAC 38, Stimergy. Credit =© Stimergy, 2018.

- **Qarnot Computing: heating with computing**
  This company, founded in 2010, is specialized in distributed computing and heat production. The objective, as with Stimergy, is to move the heat source from the data center to the apartment. Qarnot has rolled out over 800 digital radiators, the Q-Rad, in buildings like low-income housing in Balard (Paris, 15th arrondissement) and the Florestine residence in Bordeaux (in partnership with Gironde Habitat). Qarnot will then sell computing capacities to its clients. The computing will be done directly in the apartments, in this way enabling heating at a low cost. Another strong point vaunted by Qarnot is the smart building aspect since each Q-Rad is paired with an interface so that the building's consumptions and air quality can be monitored. This system makes it possible to completely meet the inhabitants' heating needs and the heating bill is paid by the clients of the computing platform. This is another approach to the computing function of data centers, permitting smart building applications.

Figure 28. Qarnot Computing heating installed in Bordeaux. Credit =© Qarnot, 2018.

As for the difficulties encountered, there is a strong chance that the involvement in a territorial project will not come from a colocation operator but perhaps more from a corporate data center more heavily sited on the territory, unless regulations force these actors to be more collective-oriented for the general interest of the territory. One example is the Stockholm Data Parks initiative launched by the city of Stockholm in partnership with the urban heating and cooling operator Exergi, the electricity operator Ellevio and that of dark fiber Stokab. It is a major commitment to territorial energy efficiency. Stockholm has developed a program that orients the location of data centers, requiring that they recover the excess heat they produce. This project is detailed later on the report.

4.3 Data centers in smart grids and micro-grids

An increasing number of large data center operators are becoming involved in energy production and in the development of private micro-grids. If their strategy is fairly opaque and remains totally secret, we can wonder if certain Big Tech companies might not have the ambition of becoming major actors on a more decentralized energy market, and especially if this orientation will also benefit the population. Between aspirations of independence and pooling, projects of different natures exist.

The energy-digital autonomous island or gated community

Microsoft and Facebook's involvement in a micro-grid program[88] is a sign that reveals their interest in energy autonomy. But for the moment, it is on the scale of their site that they are testing and creating this type of infrastructure, which at this time more resembles energy-digital gated communities.

- Microsoft has been co-financing in Colorado since 2013 a data center park whose ambition is to produce, onsite, a micro-grid and 200 MW of power. The micro-grid will function as autonomously as possible through a gas-fired cogeneration plant (CHP), a photovoltaic plant and fuel cells deployed on the site. This installation will enable data center operators to be sited there by connecting to the micro-network with the possibility of a connection to the traditional electricity network as a complement or in the event of a concern on the micro-grid. Consequently, the hierarchy of the electricity system is inverted: the onsite systems are the primary source of electricity for functioning and the traditional network becomes the backup system. The capitalistic power of GAFAM permits them to carry out energy experimentations that few other actors can undertake. This high-tech energy enclave brings to mind a sort of energy-digital gated community for the sole profit of the sector's industrialists.

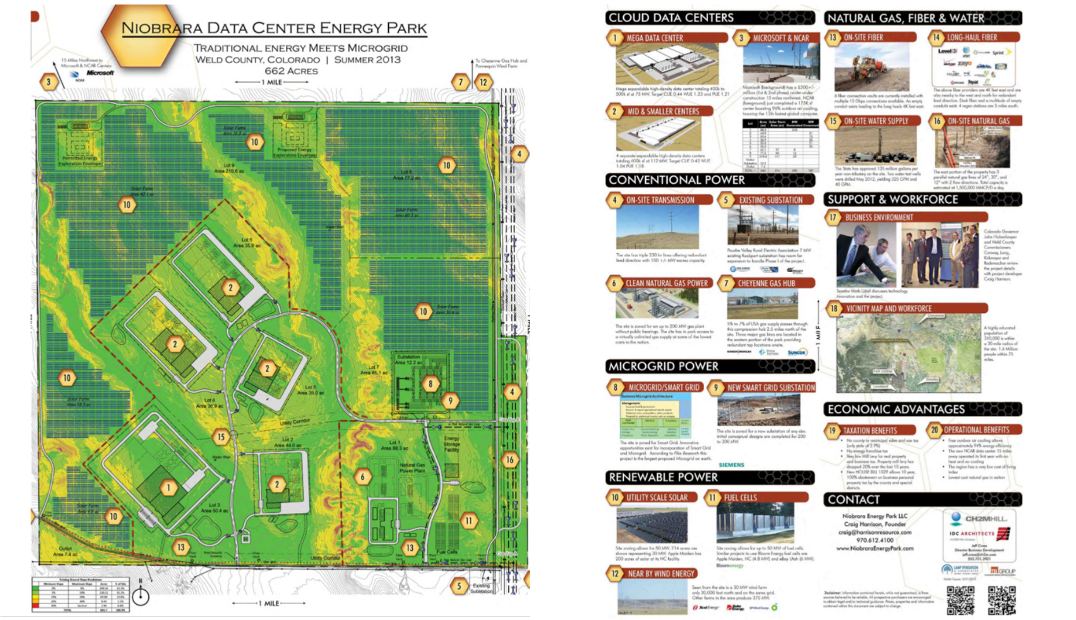


Figure 29. Microsoft data centers park. Credit =© Microsoft, 2018.

[88] https://www.greentechmedia.com/articles/read/facebook-microsoft-mobilize-50-million-for-renewable-energy-microgrids

- Microsoft is involved in a similar project for its corporate headquarters in Redmond (Washington); the company considers energy autonomy for its campus.
- Certain actors such as energy companies are specializing in accompanying actors and industrialists in the implementation, the design and operating standards of an electricity infrastructure that will permit electricity autonomy. This is notably the case for Uptime Institute, which encourages the operators to produce onsite to increase their electricity autonomy so that it is the principal energy source for the data center, the network being considered an "economic alternative." The data center operator would then control the maintenance and operation of the generators vis-à-vis the distribution network whose client it is.

From the micro to the macro-network: energy pooling

After the damage from Hurricane Sandy in 2012, electricity micro-networks or micro-smart grids became a central concern for energy actors in New York, financially supported by the state's energy department (NYSERDA). Sandy plunged a third of the New York population into darkness. 50% of the data centers were out of service in Manhattan. As for the infrastructural redundancy that characterizes them, it is a good indicator of the scope of the disaster.
Sandy accelerated a proactive policy in favor of electricity micro-grids[89] that are perceived as one of the most efficient approaches to:

- Lightening the transmission networks in New York known for their fragility, a growing demand, and therefore an increasing number of peaks to manage (let us recall that 60% of the electricity of the state of New York is consumed in the New York metropolitan region, and 40% of the electricity is produced there);
- Creating resilience in the event of a cutoff;
- Incorporating new local renewable energy micro-productions.

The scale of the buildings since the late 19th century has always favored a strong capacity in "standby" or backup electricity production. There has been a large-scale professionalization of this type of system (three days of autonomy on average). There are probably approximately 1,000 MW of backup generators (in activity) today in New York City. These generators are however very often diesel-fired and very polluting. The installation of gas-fired cogeneration plants (CHP: combined heat and power) since 2012 in the framework of the CHP Acceleration Program created by the state[90] makes it possible to offset this phenomenon while strengthening nano-grids on the scale of the building. Since 2012, 625 cogeneration plants have been installed in the state of New York and 240 in New York City. They are resources that can be mobilized by the mini-networks that sometimes include data centers.

- The New York Times building is a 52-story skyscraper delivered in 2007 and designed by the architect Renzo Piano. A nano-grid was installed on the scale of the building partially supplied by a cogeneration system designed by WSP Flack & Kurtz. Two natural gas-fired generators supply 1,400 kW of continuous electricity to the data center. The specificity of this installation is that it is continuously used as the main source of energy. Diesel motors and the distribution network provide a backup and redundancy for this system. Hot water heated by the motor provides heating in winter and also an absorption chiller in summer.

Let us point out that unlike the nano-grid that can comprise an electricity backup system on the scale of the building (interconnected or not to the traditional network), the micro-grids are deployed between several buildings on scales that vary from one neighborhood to another. We can note in the strategic planning documents a desire by the state to shift from nano to micro that is considered more energy-efficient and more relevant in terms of pooling.

[89] Navigant, 2015, *Community Microgrid Case Study and Analysis Report,* report prepared by the New York State Smart Grid Consortium. http://nyssmartgrid.com/wp-content/uploads/CommunityMicrogridCaseStudyandAnalysisReport_2015-08-133.pdf
[90] See the NYSERDA program (the New York State Energy Research and Development Authority).

Examples of pooling on urban or territorial scales:

- **Microsoft and the Black Hills electricity operator** have installed shared gas-fired backup generators in Wyoming. This installation that serves the Microsoft data center as a priority is also used for the local utility during peaks on the network. When Microsoft began negotiating with Black Hills for the construction of its 200 MW data center in Cheyenne, several problems arose. The first was that of the electricity availability requested, which was too high for the electricity supplier whose electricity mostly comes from coal-fired plants. The construction of a new plant of this type to supply the data center would require major financial investments and did not correspond to the energy footprint that Microsoft wished to give to its installation. Black Hills and Microsoft therefore made a deal: the data center will be equipped with gas-fired backup generators that could be put into operation to relieve the peaks on the local electricity network by providing it with power during peak hours. The data center consequently becomes a state-of-the-art plant, using cleaner gas-fired generators. In exchange for which, Black Hills will buy electricity on the market and dispatch it to Microsoft if there are production gaps. Microsoft benefits from a negotiated rate (when Microsoft's charge exceeds 35 MW). This rate is intended for large industrial clients that use less than 13 MW of electricity, have a large quantity of backup energy onsite and are ready to ask the electricity company to access this energy source to compensate for shortages due to peaks.

- **Portland dispatchable stand-by generation** is a smart grid designed by Portland General Electric (PGE). The principle is to remotely mobilize (diesel-fired) backup generators – 86 generators in total corresponding to 35 clients. Among them are data centers (six for Via West, two for TATA and one for ODAS) as well as hospitals, factories, universities, banks and food warehouses. Putting these generators in a network makes it possible to have a reserve of 121 MW that can be mobilized by PGE to handle part of these required emergency resources. There is pooling between these different actors and a win-win operation because PGE supplies fuel oil and handles the generators' maintenance over 15 years. In addition, during monthly tests, the energy produced is recovered by the network.

- **Salem smart microgrid** is a storage project for smart grids tested since 2010 in Salem, a few kilometers from Portland. It is a system of lithium ion batteries and inverters of 5 MW able to store 1.25 MWh of energy to supply the electricity for certain buildings including the data center of the state of Oregon. This demonstration program is part of a larger smart grid project for the Pacific Northwest, a Department of Energy research project.

In the different examples, presented, the idea is to pool dormant emergency capacities by connecting them to each other or sharing them to lighten the electricity network. The problem however remains (for certain examples) in the use of fuel oil as the primary energy source, which reduces the virtuous impact of the pooling approach in terms of the carbon footprint.

5. Citizen and public initiatives and alternative digital infrastructures

As for any network infrastructure, alternative structures correspond to the institutional, large-scale and commercial version, largely presented in the first part of this report. These alternative structures are often managed by associations or cooperatives, by citizens and enthusiasts whose aim is to enlarge access to them as well as to encourage a technical reappropriation of the infrastructure, even its transformation in terms of scale and functioning.

The digital infrastructure is comprised of three elements: networks, data centers and computer terminals. We will first bring up here the alternative and citizen initiatives in favor of a shared, open Internet network, a vector of freedom of expression and knowledge-sharing, requiring access to the Internet and communication via Wi-Fi and citizen ISP in particular. The question of storage will be discussed afterward.

This focus on the network infrastructure is necessary to grasp all the strong points, motivations and approaches of the associative and cooperative Internet actors. We will next deal with the alternative storage question (distributed on user terminals or in nearby data centers), the second phase which these ISP wish to attack, as the example of Guifi.net shows. We could then hypothesize that citizen reappropriation of storage also requires that of the network.

5.1 Citizen reappropriation of the network's digital infrastructure

Associative ISP (Internet service providers): assets for the territories

As a complement to the four main French ISP (Bouygues, Free, Orange and SFR), there are associative and cooperative ISP. In France, the French Data Network (FDN), the first associative ISP, created in 1992, was also the first structure to provide an access to the Internet for the general public at the beginning of the Web, before France Telecom in 1996. It still exists today and covers all of France, notably via VDSL. We can also cite franciliens.net in the Île-de-France, Aquilenet in southwestern France, SCANI in Burgundy and overseas in Saint-Barthélemy, Igwan.net. These associative ISP belong to the FFDN Federation.[91]

Franciliens.net is for example an associative ISP in the Île-de-France. It proposes access to the Internet via ADSL (optical fiber and Wi-Fi are being studied), but also offers an "Internet brick" to connect to the user's router, combined with a VPN, which provides access to a neutral and open Internet. This "brick" also makes self-hosting possible to store the user's own data, and for his or her e-mail.

The strong points of associative ISP are:

- Coverage of territories poorly served by the traditional operators;
- Development of local competencies and indirect jobs;
- Accessible rates;
- Involvement of volunteers and users, social link;
- Commitment on data protection.

Their potential weaknesses are:

- Limited growth dependent on the number of volunteers available;
- Possibility of service interruption because repairs handled by volunteers.

Within these ISP, some of them propose a connection that can be described as the "last kilometer": these are citizen Wi-Fi providers. In Europe, the most developed ones are Guifi.net in Catalonia (over

[91] https://www.ffdn.org/fr/membres

40,000 nodes) and Freifunk in Germany. Many other associative ISP are present in Europe and elsewhere in the world: Wlan Slovenija in Slovenia, SCANI in the Yonne, Tetaneutral in Toulouse (both in France), Ninux in Italy, Red Hook in Brooklyn, New York (see below).

Primavera de Filippi and Félix Tréguer, both researchers at the CNRS, detail in an article what Wireless Community Networks[92] (citizen Wi-Fi) are. Their strong points are on one hand technical: flexibility, resilience, autonomy of the network (see technical details on the Mesh networks in the part below). But there are also social, educational and democratic strong points. They take part in the shared governance of the Internet by contributing to the values of transparency, inclusion, the social link, technical learning and the incentive to participate in civic life. Stéphanie Vidal proposed the expression "(Re)tying the knot with the wireless," subsequently used by the researcher François Huguet in his thesis.[93] Huguet stresses that these systems favor "an economic practice that is an alternative in the service of a form of urban resilience, a pedagogic practice of community reliance." Providing access to the Internet is therefore not solely a technical gesture, but also a social, educational and economic approach and digital mediation can also be an infrastructural mediation.

The ISP SCANI, in the Yonne area, for example, has made possible the connection to the Internet of a Fab Lab, without which it could not have been able to develop its activities: the Grange de Beauvais.[94] As Benjamin Bayart[95] the former president of the FDN points out: "What competencies exist on the territories in terms of maintenance of the infrastructure, the network? How does this work, what is routing? How is hosting a website done? All of this is a fog of competency around the questions of the digital that develops or doesn't develop. We find ourselves with a digital territory that is structurally peripheral: there are people who develop websites, people who consult the websites, but they are always hosted elsewhere, a very far-away elsewhere. The associative ISP contribute to an economic diversity and therefore a certain wealth. This is what creates resilience. The fact of not relying solely on three miserable network operators, that really has the effect that competency in terms of infrastructure on the network is extremely centralized in a few Paris locations. It's not quite as caricatural as that, but it really isn't that far from the truth."[96]

Creating a place for these actors, certainly small, in French digital landscape that is not very diverse today, seems important, insofar as a more local, better informed management, handled by its own users, can favor more sober, economical and need-adjusted practices.

The Mesh networks, an Internet access for everyone

The Mesh networks are most often the basis of Wireless Community Networks, sometimes accompanied by the Commotion software enabling their creation. Primavera de Filippi and François Huguet present the Mesh network as "a group of communicating devices connected to each other in a distributed manner, wireless and without any central hierarchy."[97] All these terminals, cellphones, computers, tablets communicate with each other, between peers, through Wi-Fi, using a dynamic routing protocol that makes it possible, when a terminal is turned off, to configure a new route for the data packets. Each person consequently becomes a relay for the network. The authors of the article believe that the Mesh networks are a breakthrough technology "compared to the traditional wireless centralized solutions with a base station or with mobile telephony systems." It is a genuinely decentralized communication system that can function without the Internet, and can share the Internet connection of its users with others.

[92] Primavera de Filippi, Félix Tréguer. "Expanding the Internet Commons: the subversive potential of Wireless Community Network", in *Journal of Peer Production*, issue no. 6: Disruption and the Law, January 2015. https://halshs.archives-ouvertes.fr/halshs-01306630v2/document
[93] François Huguet, *(Re)coudre avec du sans fil. Enquête sur des pratiques de médiation infrastructurelle,* thesis under the direction of Annie Gentès and Jérôme Denis, Paris ENST, defended in June 2016. Notably see the résumé of the thesis onhttps://medium.com/@francoishuguet/re-coudre-avec-du-sans-fil-ae0d4f28888c
[94] https://blog.scani.fr/index.php/2018/07/05/grange-de-beauvais-connectee/
[95] Interview with Benjamin Bayart, September 20, 2018.

[96] For more resources on the subject: https://communitytechnology.github.io/
http://bibliotecadigital.fgv.br/dspace/handle/10438/25696
[97] Cécile Méadel and Francesca Musiani (dir.), "Les réseaux Mesh," in *Abécédaire des architectures distribuées*, Presses des Mines, Paris, Collection I, 2015.

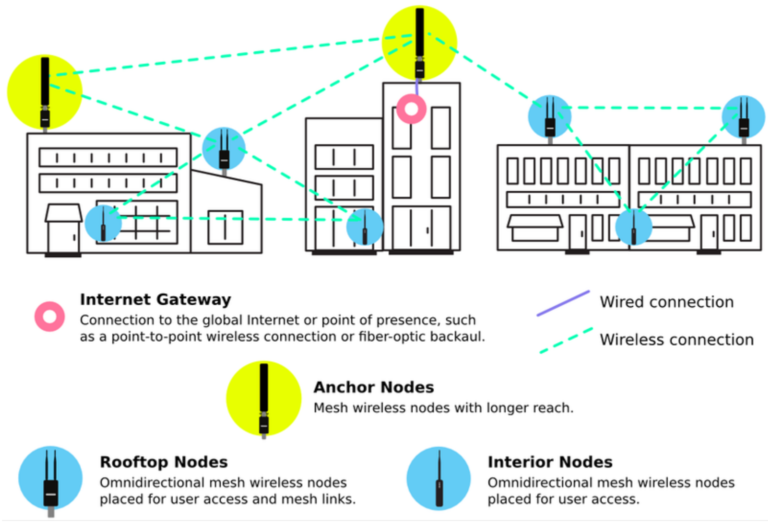


Figure 30. Explanatory diagram of the Mesh system
https://www.newamerica.org/resilient-communities/flexible-future-ready-networks/rise-nyc/

The strong points of the Mesh networks are to present "a tolerance and major robustness to network cutoffs and breakdowns in general," to roll out at a low-cost (less expensive than satellite telephone systems, for example) and without terminals with advanced technology, and to constantly self-optimize. These networks also enable citizen to enter the black box of digital networks, to train themselves and to reappropriate digital communication infrastructures.

There are also limits to these systems: possibility of loss of data, absence of infrastructures if there are not enough terminals in operation, transmission errors or security problems. At this stage, these networks cannot replace the traditional telephone networks (GSM, global system for mobile communications) and have a local scope that is often modest but that is very interesting in zones without infrastructures. Consequently, in the Republic of South Africa and Kenya, the Mesh Potato project was developed, and the Feem project in Cameroon. These networks are also interesting in the event of a natural disaster, such as Hurricane Sandy in New York, discussed earlier, but also in Haiti, Thailand and the Philippines, or as a local development tool: in Detroit since 2012 and in Montreal with the "île sans fil" ("wireless island") network. Countries and regions where Internet cutoffs occur of that censure the Internet can also find an efficient alternative in the Mesh network, as in Egypt in 2011 or in Catalonia in 2018, for example.

New applications are being developed today blending the Mesh and blockchain technology such as Rightmesh,[98] incorporating incentives to make one's terminal available to the network via tokens that also permit goods and services to be paid for.

These systems make it possible to share one or more Internet connections, without all the users (and even a minority) having to pay for an Internet subscription. They therefore arouse the hostility of the commercial ISP and traditional telephone operators. Moreover, these networks feature an anonymity that frightens governments in addition to darknet-type abuses and a too great freedom of the populations for the most authoritarian governments. In France, the pooling of an Internet connection and therefore of the Mesh networks, has been largely hindered[99] by the fact, on one hand, that the Internet user making his connection available must keep traces of his or her "guests," and, on the other, that the HADOPI 2 law obliges the user to secure his or her connection, under penalty of a fine or cutoff.

Furthermore, the networks must be able to use the available Wi-Fi frequencies, but the foreseeable growth of the IoT that also functions with the Mesh technology can saturate these networks in the future. The authors of the Mesh article thus point out that it will then be necessary for the government to free "whitespaces" (unused radio frequencies) to make room for citizen and associative operators.

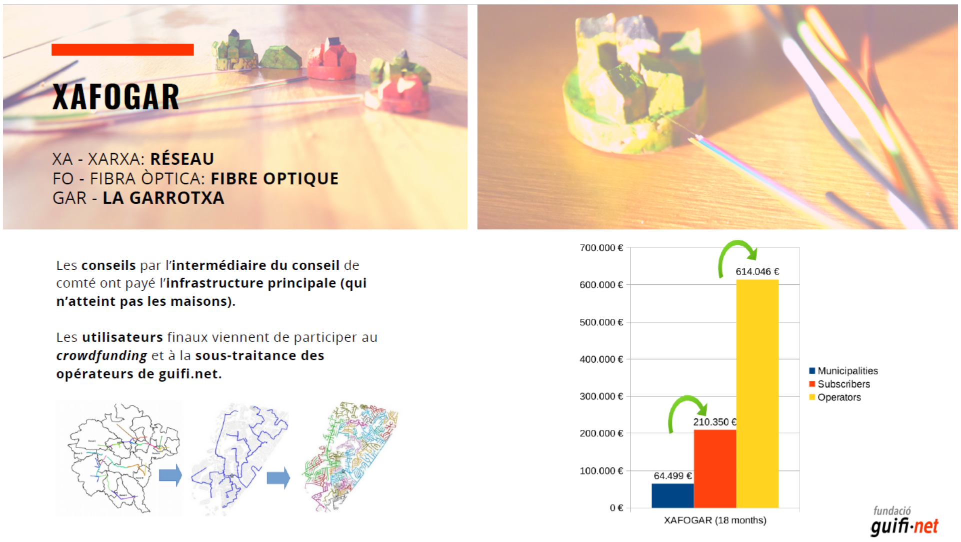
[98] https://www.rightmesh.io/technology
[99] Decree of March 24, 2006.

5.2 Guifi.net: an infrastructure, a common

In the milieu of alternatives for a free, sober and decentralized Internet, the initiatives often bring together small groups of people mobilized around systems that have trouble (for technical and regulatory reasons) moving beyond the circle of initiated activists. Development or a jump in scale is not obvious in a digital world dominated by the telecom multinationals and an injunction to increase clicks. In this context, Guifi.net is exceptional., This foundation was able to develop an infrastructure on the principles of commons as defined by the economist Elinor Ostrom and a resolutely different service offering that is constantly growing.

Guifi.net is an Internet network created in 2004 to meet unsatisfied local Internet connection needs in Catalonia. It started on a small scale, but in 2007, the members realized that private actors were proposing services based on the Guifi.net infrastructure without helping to make the network durable. Guifi.net then decided to create an economic and governance model reconciling the development of services, job and company creation, services for users and the durability of the infrastructure, notably with the invention of a license (or charter) that must be accepted by all the networks' actors.[100]

Today, the network is managed as a common, on a participatory, transparent and open model. Everyone can participate, including private actors, but in the framework of a well-defined economic model, with a compensation and equalization system that makes it possible to intervene in different, more or less profitable territories, but also to maintain and perpetuate the infrastructure. The Guifi.net Foundation was created to guarantee the functioning of this model as a common. Four or five service operators are major contributors to Guifi.net for an amount of 200,000 to 300,000 euros a month, and in total, 30 service companies have been incubated by the foundation (with the creation of jobs).[101] There are several thousand subscribers and volunteers who also participate in the network. About 20 million euros have been collectively invested (Guifi.net, local administrations, users) since 2004 to develop the network.



Today, it is half composed of Wi-Fi, half of optical fiber. Guifi.net must however very actively fight to have the right to develop this infrastructure, faced with the dominant telecom operators and European regulations that are unfavorable to it.

[100] Roger Baig, Lluís Dalmau, Ramon Roca, Leandro Navarro, Felix Freitag, Arjuna Sathiaseelan, *Making Community Networks Economically Sustainable: The Guifi.net Experience*, in Proceeding GAIA 16, Proceedings of the 2016 workshop on Global Access to the Internet, 2016. http://people.ac.upc.edu/leandro/pubs/baig-sigcomm.pdf
[101] Interview with Roger Baig of the Guifi.net foundation, November 2018, Barcelona.

CARACTÉRISTIQUES TECHNIQUES DU RÉSEAU

RÉSEAU D'ACCÈS

Il arrive dans les foyers et l'objectif actuel du réseau est de mettre fin à la fracture numérique, de se connecter à tout le monde.

TRANSPORT TERRITORIAL

Les infrastructures publiques existantes sont réutilisées:routes, poteaux, lignes électriques ...

TRAFIC GLOBAL

Point d'interconnexion avec l'internet mondial. Jusqu'à 10Gp symétrique.

On the data storage question, Guifi.net hosts its data today in a traditional colocation data center, in which one of the Internet backbones arrives, in the port zone of Barcelona. There is no hosting for third parties, but this is envisaged as a future service. Guifi.net is developing a cloud common project[102] (called Cloudy) with the same social organization as for the network (a common). Cloudy is an edge computing-type service with storage distributed in the Guifi.net users' machines. The simulation of the economic model of a cloud common has led to positive conclusions. Next will come implementation.
These digital technologies reappropriation initiatives follow a movement and dynamics comparable to those that can be observed on renewable energies by large cooperative and citizen groups (sometimes supported by the local administrations) in Europe. Laure Dobigny, specialized in the sociology and anthropology of techniques and technologies, studied the effects of relocating renewable energies on user behavior through the analysis of autonomous rural communes. She asserts that energy management that includes and involves, at a given moment in the process, the inhabitants participates in a sobriety dynamic.[103] This is what Laure Dobigny observed in the rural areas where the installation of technical systems on a smaller scale has permitted, by modifying uses, a reduction in consumption.

There is reappropriation in this dynamic, whether it concerns energy or the digital, the determination to organize a "common" and citizen support (inhabitants, local economic actors) can be increased by institutional and/or municipal backing.

---

[102] Roger Baig, Felix Freitag, Leandro Navarro, *Cloudy in guifi.net: Establishing and sustaining a community cloud as open commons*. https://www.sciencedirect.com/science/article/pii/S0167739X1732856X

[103] Laure Dobigny *Le Choix des énergies renouvelables. Socio-anthropologie de l'autonomie énergétique locale en Allemagne, Autriche et France*, thesis under the direction of Alain Gras, Université Paris 1, 2017: "L'autonomie énergétique: acteurs, processus et usages. De l'individuel au local en Allemagne, Autriche, France," in Dobré, M., Juan, S. (eds.), *Consommer autrement. La réforme écologique des modes de vie*, Paris: L'Harmattan, 2009 p. 245-252.

5.3 Extending the low-tech and citizen dynamic of the networks to data storage?

"It is starting at the moment when you want to put the e-mail of 2 billion people in the same spot that the problem occurs."
Benjamin Bayart, former president of the FDN
(interview, September 20, 2018)

The potentials of distributed storage to reduce the energy and spatial footprint of the digital

The functioning of the Internet, before the Web, and before data centers, was based on self-hosting and peer-to-peer functioning, in which the intelligence (technical resources and contents) of the network was in the ends (end-to-end functioning), that is, in the users' computers. The creation of the Web and its explosive growth in the 1990s caused the development of more centralized technical architecture, creating increasingly powerful intermediaries between the Internet users. As early as the 2000s, the Gnutella project proposed peer-to-peer storage. This proposal has reemerged in the last several years faced with the risks brought by the ultra-concentration of data by the Cloud and hyperscale data centers. Certain software programs, cloud solutions or services now propose reusing peer-to-peer functioning or distributed storage on one hand, or facilitating self-hosting on the other.

Peer-to-peer cloud solutions are currently appearing. As the researcher Francesca Musiani[104] stresses, "the central idea underlying these systems is that the files and contents downloaded by users in the system are stored, totally or partially, on a storage cloud composed partly of each user's hard drive, linked to each other in a P2P architecture." Security questions are managed by encoding and fragmentation processes, as well as duplicate systems to compensate for the users' machines that connect and disconnect. There can also be, moreover, a swapping of hard drive space against the online space as in the case of the Wuala project[105]: "a user can exchange the unused space of his or her own computer against the storage space on the 'user cloud' provided that the user stays online for a certain amount of time each day" (p. 212). What remains is that these systems are still experimental and raise questions on the confidentiality of the data and the security of the equipment. They are however part of a movement to rediscover the strong points of peer-to-peer computing, which, moreover, can contribute to "answers to question on bandwidth allocation, the balance of traffic, the efficiency of distribution" on the Internet network more generally.[106] For Primavera de Filippi,[107] cloud computing, despite its strong points in terms of flexibility and data availability, raises a certain number of challenges on security, private life and the autonomy of Internet users. She points out several initiatives that attempt to meet these challenges through decentralized alternatives, while keeping flexibility and availability. She also cites several peer-to-peer cloud projects: the open-source software SlapOs, OwnCloud and Cozy Cloud. These projects remain relatively confidential at this stage, but constitute interesting potentials for users whose growing distrust faced with GAFAM in particular, in regard to fraudulent uses of their data (Cambridge Analytica scandal, among others). Self-hosting services, with remote consultation of the user's data, is also developing, via Yunohost, for example.

These decentralized and distributed clouds therefore favor distributed data storage, and reduce the need for large data centers. They thus have the potential to partially lessen the spatial impact and ground footprint of these installations, and to make it possible, like the offerings of Qarnot with the Q-Rad and Stimergy's digital heaters, to better spread storage capacities over the territories.

---

[104] Francesca Musiani, "Stockage distribué," in *Abécédaire des architectures distribuées*, Cécile Méadel and Francesca Musiani (dir.), Presses des Mines, Paris, Collection I, 2015. p. 209.
[105] This project was stopped in 2015, because no economic model was found.
[106] Francesca Musiani, Valérie Schafer, "Le modèle Internet en question, 1970-2010," in *Flux*, 2011/3 no. 85-86, pp. 62-71.
[107] Primavera de Filippi, "Cloud computing," in *Abécédaire des architectures distribuées*, Cécile Méadel and Francesca Musiani (dir.), Presses des Mines, Paris, Collection I, 2015, p. 49.

We can equally raise the question of the energy impact of distributed storage. Several hypotheses are possible but there is little research on the subject at this stage to confirm them[108]:

- The absence of backup infrastructures (backup generators, batteries), large air-conditioning systems but also electrical equipment like inverters reduces the expense of the initial material (production), the gray energy used and the energy used in the event of a breakdown. However, we can imagine that redundancy will be attained through the peer-to-peer networking of more machines.
- Having one's storage at hand favors a more adjusted functioning (not oversized, no zombie servers…) and avoids the drawbacks of dematerialization that gives users the impression of having access to infinite storage spaces.
- Distributed storage is done a priori more locally (and not on other continents than the place where the users live), the data to be stored traveling less on the communication networks; we can then suppose less energy used on the network.
- "IT refresh" processes that are done every other year in the colocation data centers and the cloud are probably less frequent in the case of individual machines. Here too, we could hypothesize a savings in material and gray energy at the production stage of computer equipment, and therefore a lower production of computer waste as well.

Complementary studies seem necessary on this subject in comparing the services provided in terms of storage. It will therefore be necessary to take into account the electricity supply for these infrastructures and the possibility of (self) consumption (or not) of renewable energies.

Associative/cooperative data centers of proximity

The small data centers that we could describe as "proximity," like a store or a facility, are an option also to be explored.

Among the alternative hosting actors, a new collective was created in 2016 in France: the Chatons (kittens). As presented on the site, it is a "Collective of Alternative, Transparent, Open, Neutral and Supportive Hosting actors". It brings together structures wishing to avoid the collection and centralization of personal data in digital silos of the kind proposed by Big Tech." This collective is consolidated around a charter that guarantees users the respect for the values displayed: alternative, transparent, open, neutral and solidarity. Ecological and energy aspects are not mentioned in the charter, which does not prevent the projects, individually, from incorporating these approaches. Experimentations are also emerging for data centers of proximity, more low-tech, autonomous and locally managed: this is notably the case of an experiment at Rutgers University in New Jersey (mentioned earlier in the report).

We develop, below, several examples of alternative operators that have mini-data centers.

Example 1: SCANI, the Yonne department
SCANI is a cooperative company of collective interest (SCIC) that rolls out, manages and maintains a communication network and Internet access, and at a later date storage services, throughout the Yonne department and that is owned by its users: individuals, companies and local administrations.[109]

Like Bruno Spiquel, one of the active members of the cooperative stresses, there is relevance in installing small local data centers, as close as possible to uses: "As difficult as it was 10 years ago to find places with connectivity favorable to hosting a machine, now, between the cable, VDSL and fiber, it is rather easy to find over 50-100 Mbps of capacity, easily enough to pile up dozens of websites, including the most complex."[110]

Better territorial connectivity thus makes it possible to better spread out data storage capacities in local data centers. Consequently, SCANI operates three of them directly and occupies two that belong to third parties (Virtual Networks in Auxerre). The cooperative uses them for its internal needs, but is

[108] A research track of the Groupement de Services EcoInfo explores the questions linked to the energy impact of storing one's data on a local hard drive rather than on the Cloud.
[109] "Whatever the use made of the connection or the person who subscribes to it (individual, company…), the rate is identical: €30 a month, tax included," (consulted online on December 10, 2018), www.scani.fr
[110] E-mail exchanges with Bruno Spiquel, November 2018.

currently envisaging creating a third-party associative or cooperative structure that could manage these storage spaces for external needs as well.

It is interesting to examine the three facilities that SCANI operates directly:

- The first is a lightweight garden construction, converted into a data center, that can hold three bays (a single one is in service and is a quarter filled). At this stage, the space is not air-conditioned. It is equipped with an inverter. It will be improved as its needs grow.
- A former 12 m² telecom shelter, the propriety of a mayoralty that has lent it to the cooperative. This five-bay space is completely equipped (electricity and air-conditioning). A half-bay is occupied today. We can see here the conversion potential of small-scale telecom real estate, probably vacant in many territories, notably rural.
- A technical space of 30 m² in a former military building, currently being transformed by SCANI, which will act as an optical head for a FTTH hyper-local network and a data center with a maximum capacity of three to four bays.

For Bruno Spiquel, when data is hosted locally, for a close community of users, "the taking into account of the energy issue is immediate, but not necessarily to 'help reduce climate impact,' often just for electricity and/or financial sizing or more marginally, available space." The modest means of these actors therefore leads to frugality in terms of the equipping, laying out and functioning of these local data centers.

Example 2: Aquilenet in Bordeaux

Aquilenet is an associative ISP that wished to supply a neutral and open Internet. It also proposes hosting[111] and was able to install its own associative data center with a free format ("the mezzanine")[112] in a space in the fall of 2017, whose electricity is provided by a supplier that only proposes renewable energies.

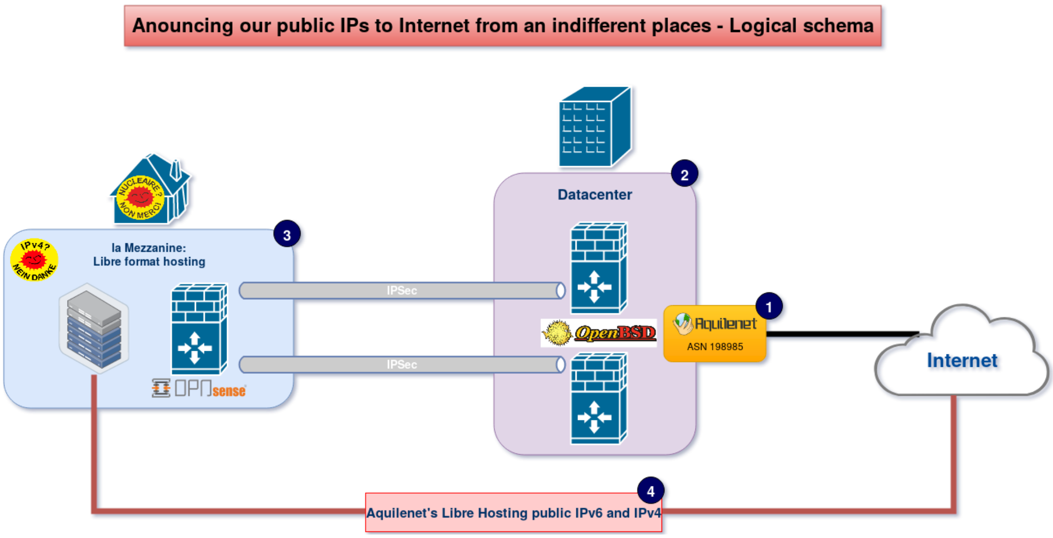


Figure 31. Storage architecture at Aquilenet
Source: Aquilenet Internet site

For information, the monthly prize of hosting on the Mezzanine is:

- Between €5 and €10 a month for a small machine (NUC, netbook, NAS, Raspberry Pi, etc.);
- Between €15 and €20 for a laptop (consumption of 100 W maximum with an average consumption of 30 W).[113]

Aquilenet also hosts its servers in a professional data center (Cogent). The rate is €100/month per rack.

[111] https://atelier.aquilenet.fr/projects/services/wiki/Hergementlibre
[112] https://www.aquilenet.fr/actualit%C3%A9s/la-mezzanine-histoire-dun-centre-dh%C3%A9bergement-associatif-au-format-libre/

[113] Source: https://www.aquilenet.fr/services/h%C3%A9bergement-serveur/ consulté en décembre 2018

Example 3: Tetaneutral in Toulouse

Tetaneutral is an ISP, Web host and operator in a not-for-profit association form, hosted since 2011 at Mix'art Myrys, an artistic and cultural structure, in a former hangar in a Toulouse industrial zone of a total area of 6,630 m^2, made available through the crossed financing of local administrations (city of Toulouse, Toulouse Métropole, the Haute-Garonne department, the Midi-Pyrénées region and the DRAC). The site is divided into 4,200 m^2 of workshops, 430 m^2 of offices and 2,000 m^2 of exterior spaces.

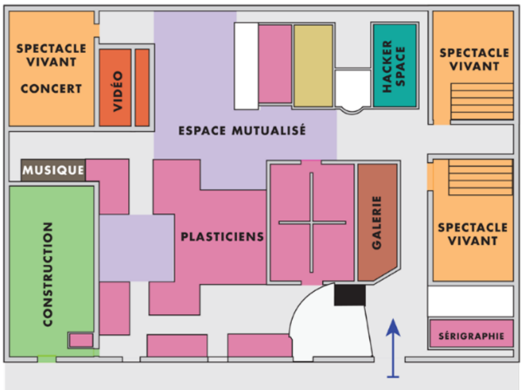


Figure 32. Ground-floor plan of Myrys

The association has two computer rooms, on the upper floor of the building, near the offices, with a connection to a neighboring data center operated by Cogent. The association rented a rack unit in a bay, with a transit contract and had the right to make a hole to run an optical fiber from the bay to Myrys. Moreover, Tetaneutral co-operates a room in a traditional data center, operated by Fullsave, which offered them an "associative" room, outside the ultra-secure zone, difficult to air-condition. It is a sort of residual space in the building that could be constituted by adding a partition, a door, an electricity and a fiber inlet, and therefore provide a space at a low cost. The association pays an inexpensive rent and its electricity consumption. In these rooms, Tetaneutral refuses to host machines that consume too much electricity and makes its members aware of electricity consumption questions. It is very interesting to note here a complementarity between traditional and associative data center hosting, as well as the optimization of the building's residential spaces

Tetaneutral has recommended rates, which implies that there are de facto social rates. They are:

- Hosting of a virtual machine: €10/month;
- Hosting of a physical machine:
  - Small machines (NUC, Brix, Zotac, netbook, nettop, NAS, SheevaPlug, Raspberry Pi): €5 to €10/month;
  - Laptop: €15 to €25/month (€20/month for a consumption of 100 W maximum with an average consumption of 30 W).[114]

These new small-scale infrastructural places are not a return to the cabinets of companies in the 1990s, but a potential relocation of the Internet as close as possible to users, in the heart of cities. They thus redefine the idea of a public facility in the territories, and prefigure a new geography of the digital that is more local and more distributed.

<u>The strong points of data centers of proximity</u>

Technical

- Less backup equipment therefore less consumption of materials and gray energy in the production phase and less floor occupancy;

And as for distributed storage:

- Having one's own storage at hand favors a better adjusted functioning (no oversizing, no zombie servers…) and avoids the drawbacks of dematerialization that gives users the impression of having access to infinite storage spaces;

[114] Source: https://tetaneutral.net/adherer/ (consulted in December 2018).

- Storage is done more locally (and not on other continents than the place where the users live); we can suppose less energy used on the network;
- "IT refresh" processes that are less frequent due to modest means. Here too, we could hypothesize a savings of materials and gray energy at the IT equipment production stage and therefore less production of IT waste as well.

This limitation of the consumption of IT equipment corresponds to the recommendation of the white paper by FING, IDDRI and WWF[115] on "lengthening to five years the duration of the guarantee for digital equipment" and the recommendations of The Shift Project report on energy and the digital published in October 2018.[116]

Economic and social

- Local economic and social development: hosting services accessible for local activities, SME;
- Training volunteers in the maintenance of digital infrastructures can be a springboard for employment.

Urban

- No urban and spatial concentration effects of data centers (therefore no heat island effect, no pressure on the local electricity system and land resources);
- Greater resilience to climate events than large-scale centralized infrastructures.

<u>Their weaknesses</u>

- Potentially lesser availability which implies greater tolerance from users who have a breakdown;
- Lower capacity to grow rapidly (but this is not necessarily the aim).

Consequently, storage distributed in computer terminals and small data centers of proximity comprise a possible solution for reducing the spatial (ground footprints, notably) and energy impacts of data centers.

If today, data hosting, storage and processing remain mostly in the hands of commercial operators, civil society operators are developing and public actors are also deploying their own infrastructures. The development of public data centers could therefore constitute a perspective making possible a more coordinated relationship to the territories, accompanied by pooling and energy savings requirements.

5.4 Data labeling project for higher education and research

For the last several years, the French government has been undertaking a computer resources rationalization movement for the higher education and research sector.[117]

In November 2015, the digital orientation committee[118] (CODORNUM) launched a movement to restructure the digital resources of higher education and research with a recommendations report. One of these recommendation was the rationalization of existing machine rooms in this sector. The multiplication and aging of small sites over the years has brought about both a problem of interoperability between the different departments of universities and superfluous energy expenditures. This approach converges with the actors' desire to pool certain resources and competencies, for example, with the

[115] *Libre blanc Numérique et Environnement. Faire de la transition numérique un accélérateur de la transition écologique.* FING IDDRI WWF.2018
[116] *Lean ICT* report, The Shift Project, 2018.
[117] Inventory after the INFOTHEP 2014 study: several thousand machine rooms in the higher education and research sector appear to have a low energy efficiency (PUE of 1.5 to 3.5), often unknown total costs, and sometimes have incidents with losses of data. https://succes2017.sciencesconf.org/data/2017_Journe_es_Success_16octobre_DGRI_V2.pdf
[118] Decision-making body whose vocation is to propose orientations at a high strategic level on subjects related to the digital transformation. The CODORNUM is composed of four steering committees that work on different themes: information systems, training, documentation, and scientific and technical information and the steering committee on digital infrastructures, called InfraNum.

arrival of a need for archiving.[119] This concerns the emergence to the maximum of a data center for a future large region.

Objectives:

- Spatial rationalization on the national and regional level with the closing of IT rooms;
- Development and pooling of new services between local, especially public actors (higher education and research and beyond: teaching hospitals, territorial administrations, etc.);
- Creation of distributed competency hubs;
- Transition to a hybrid cloud for higher education and research.

This new storage and computing infrastructure would be under the responsibility of regional actors.

Pooling of university digital infrastructures

The first step is to rely on a higher education and research network of four data centers on the national level and 13 data centers on the regional level. The four national data centers are to be built on the sites of four higher education and research computing centers: CC-IN2P3 in Villeurbanne, the TGCC in Bruyères-Châtel, the CINES in Montpellier and the IDRIS in Orsay.[120]

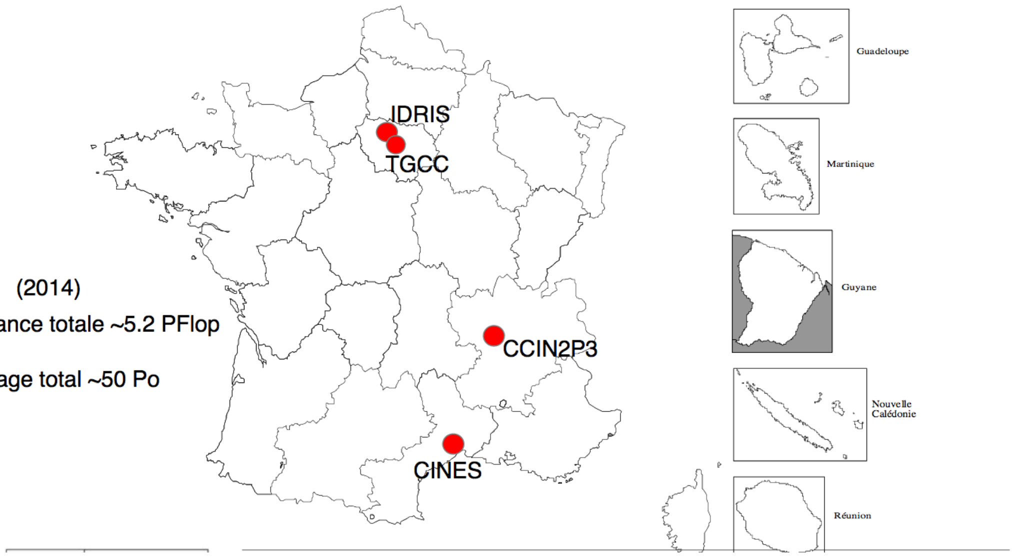
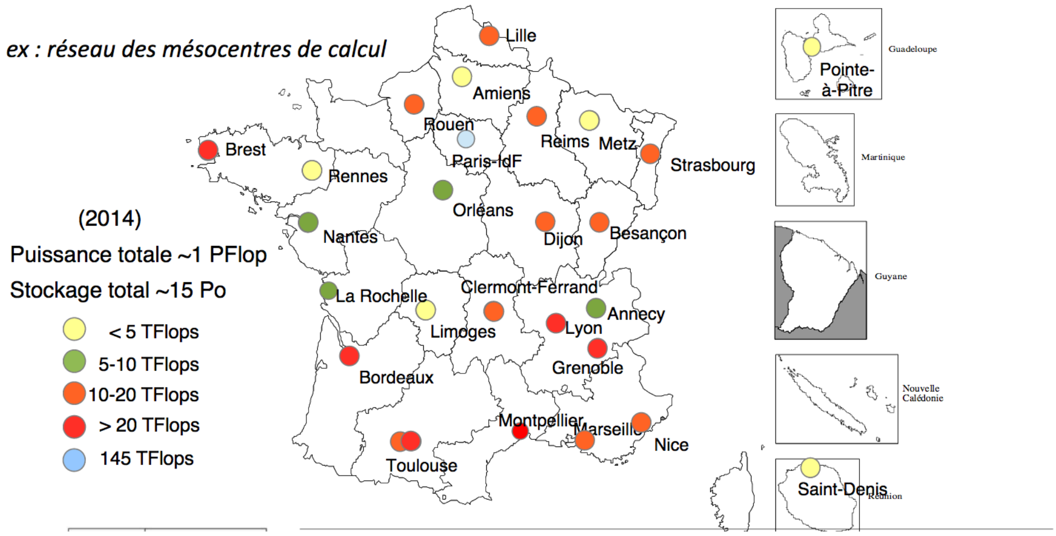


Figure 33. The 4 national data centers: TGCC in Bruyères-le- Châtel, CINES in Montpellier, CC- IN2P3 in Villeurbanne, IDRIS in Orsay =© Ministère de l'Enseignement supérieur et de la Recherche.

The 13 regional data centers will be built based on the network of mid-size computing centers, the governments regional network of IT services; the rectorate network; initiatives underway in the territorial administrations, the COMUES and the CPER projects.[121]

[119] Interview with François Pellegrini, October 4, 2018 in Paris: "Archiving problems are raised and therefore there are major needs, for something that was new for us. The national or departmental archives know what to do but as academics, we don't know what to do, but we now need to know."
[120] Presentation by Pascal Fouillat during the "Challenges of large research infrastructures in the globalization of knowledge" days, March 23-24, 2016.
[121] http://calcul.math.cnrs.fr/IMG/pdf/menesr_crouzet.pdf



This initiative would make it possible to meet several needs:

- Network needs to deploy regional data centers: quality of service, broadband connections between data centers and schools;
- Needs for pooling research organizations, in liaison with the national research infrastructure strategy;
- National structuring needs: EuroHPC /EOSC/GO FAIR in the European context.

All these changes fit into a context of territorial reform with the creation of new regions and regional platforms of digital public services by the metropolitan areas and regions. The labeling by InfraNum of a single data center in each of the 13 regions would make it possible to finance these data centers, objects of a regional dialogue (that benefit from contracts in the framework of the CPER 2015-2020 federal-regional plan). Out of the 10 projects presented, three were selected by the labeling committee in 2018. They concern projects in the Bourgogne, Franche-Comté, Provence-Alpes-Côte-d'Azur and Auvergne-Rhône-Alpes regions.[122]

The Université de Bourgogne has campuses in six cities (Dijon, Auxerre, Nevers, Macon, Chalon-sur-Saône and Le Creusot) and 11 sites. In 2014, faced with the aging of its server room, built in 1996, and the evolution of its needs, the university decided to build a new data center in a dedicated building with 110 m^2 of space reserved for the servers. This notably made it possible to reduce the university's energy footprint using the most recent technologies but also to meet the requirements of data security and sovereignty. This data center subsequently obtained the label "Regional data center for higher education and research."

The Université de Bordeaux undertook a reflection on pooling digital infrastructures by going beyond the limits of the university and working with all the public representatives of the Nouvelle-Aquitaine region. This raises the question of the governance of this very ambitious project, a governance that goes beyond the framework of higher education and research. François Pellegrini, commissioner at the CNIL (French data protection authority) and former vice president for the digital at the Université de Bordeaux, promoted the creation of a network of eight pooled data center rooms with a governance shared between the region's different actors.[123] The Nouvelle-Aquitaine is an enormous region and there are constraints on the broadband coverage of this territory. Consequently, connecting a large broadband data center, anywhere in the region, to all the users would not be optimal. It is for this reason that a reticular system was envisage with a territorial network of eight rooms. But this project was not validated in the first phase. "They didn't want eight data centers, they wanted one large one, it is a somewhat Jacobin vision.

[122] Presentation by Marie-Christine Plançon, project manager for the modernization of digital infrastructures and services at the Ministry of Higher Education and Research, at the 2018 Data Computing days on "the modernization of digital infrastructures and services of higher education and research."
[123] Interview with François Pellegrini, October 4, 2018 in Paris.

Everything had to be reexplained, which is underway."[124] Another problem on this site is the location because the campus is below an air corridor, which will not permit the installation to become a high-level data center.

François Pellegrini summed up the difficulties as follows: "For the moment, the metropolis of Bordeaux rented space in an existing data center, but there was no public project in which they were interested, in which they would get involved. It's really a question of timing, of process, of comprehension of the project. […] These objects are poorly understood by the politician. In addition we, in the data center, also host a super-calculator. People don't understand the connections between its financing, the financing of the data center. The super-calculator of the next generation will be in the data room. The third will be in a data center, an object that will also be a Nouvelle-Aquitaine super-calculator."

The Université de Grenoble also tried to get an entire varied ecosystem (city, hospital, university, rectorate, etc.) to work together to pool digital resources. The project began in 2008. As in Bordeaux, the question of governance is complex because the entities have different supervisory ministries. The InfraNum labeling committee selected the data center project of the Auvergne-Rhône-Alpes region, proof that an advanced concerted project exists with identified needs, but no site has been announced for the location of this data center. Shared governance and the multi-supervisory approach remain complicated and energy reduction has not really been focused on.

From the university to the territory: complexity of a multi-supervisory approach

This labeling project highlights a desire for pooling digital resources on the territory. François Pellegrini points out that a "data center is a modular object. What is to be pooled is the electricity supply, the air-conditioning and the security perimeter. For the rest, for the floor area, it is sufficient to install partitions and locked doors and each person manages his or her own space. We have reserved 7,000 m² and we are building module by module as people arrive." However, the projects that have received a label are those that have not pooled anything. This clearly shows the project's difficulty and the lack of a mediation entity that can accompany the actors.

Today, there are many difficulties and curbs:

- Choosing the object's size and perimeter;
- Finding a site that is not necessarily on campus (because the data center must be protected from demonstrations and student movements);
- Evaluating technical needs for economies of scale and quality of service;
- Defining the multi-actor, multiuse dimension and creating trust between the partners and the sharing of competencies.
- Specifying the legal structure: a public interest group (GIP), an economic interest group (GIE) to bring the private sector in?

This issue of the configuration of digital infrastructures is not reserved for higher education and research actors but concerns all the public actors.

The difficult emergence of public data centers

Public actors and the Cloud
Public actors have the possibility of migrating to the Cloud or having recourse to the hosting offering of a private actor. However, this solution raises an increasing number of questions on the location and sovereignty of the data.
The question of reversibility can also be a constraint: the local administration must be able to remain the sole master of the totality of its data, which remain its property. All this is accompanied by the constraints of renewing public contracts: after three or four years, the local administration must once

[124] Ibid.

again put the offerings in competition and if necessary, must be able to recover the totality of its data and move them to another operator while ensuring service continuity.[125]

What solutions for local administrations?

The General Division of Companies (linked to the Ministry of the Economy, Industry and the Digital), the General Commissariat of the Equality of Territories (linked to the Ministry of Territorial Cohesion) and the Caisse des Dépôts et Consignations consequently participated in the publication in 2015 of the *Guide sur le cloud computing et les data centers à l'attention des collectivités locales*. This guide presents solutions for cloud computing and pooling infrastructures that can exist for local administrations.[126] Data centers "of proximity" are highlighted as well as projects for pooling infrastructures, services and competencies between administrations and with different territorial scales, favored access to hosting services for smaller-scale administrations that do not necessarily have IT and logistics resources. In the same way as for the higher education and research examples, this solution would make it possible to meet the needs of administrations and public actors while permitting energy savings on the infrastructures. The regional councils could play a major role in these initiatives.

The limits of the initiative

In the case of higher education and research, the process of labeling a single regional data center does not necessarily take the specificities of each region into account. In the case of the Nouvelle-Aquitaine region, the largest in metropolitan France, it would seem that the solution of several data centers organized under a shared governance better responds to the region's constraints. This desire to have a single regional data center could also bring about a hyper-concentration of the digital activities of a regional capital, at the risk of leaving the rest of the territory on the sidelines.

The directives for this pooling movement only apply to the higher education and research data centers. The large public data center projects in regions like Nouvelle-Aquitaine will therefore only be concretized if there if is a strong desire by all the ecosystem's actors (regions, departments, communes, rectorates, universities…).

If the world of banking and finance, which represents a large part of Internet traffic and the computing and storage capacities of data centers, is probably not ready to turn to public or more distributed infrastructures, there seems to be opportunities here for civil society, associations the social and solidarity society to take over this common good – the Internet.

The scale and modalities of the governance of these infrastructures are major societal subjects at a time when the social ideal of the large infrastructure as an edifice of public service, which combined economies of scale, technical stability and quality service for the greatest number of users, has been destabilized since the 1990s by the private capital of the liberal economy.[127] The centralized technical object is the victim of new assemblies and movements away from what gave it its values.

The overhaul of public service based on commons,[128] remunicipalization or deprivatization movements on municipal or regional scales are multiplying in Europe for energy services but also digital services, as in Stockholm and New York.

The support of territories in access to a free and open Internet is as indispensable as a broader reflection on the data center object and the related digital system; to better measure the environmental impact of technical choices compared with the expected social value; and to move toward more reasoned and sober digital practices that also take degrowth into consideration.

[125] For more information: *Guide sur le cloud computing et les data centers à l'attention des collectivités locales*, July 2015.
[126] Idem.
[127] Graham, S., Marvin, S., *Splintering Urbanism,* London, Routleddge, 2001.
[128] Alix, N., Bancel, J. L., Coriat, B., Sultan, F. (eds.), *Vers une république des biens communs*, Éditions Les liens qui libèrent, 2018.

6. Integrated approaches

The question also concerns promoting integrated public approaches in which land, energy, urban and economic questions are taken into account: this is the case of the Data Center Parks in Stockholm and the approach of the Red Hook neighborhood in Brooklyn, New York.

6.1 The Data Center Parks of Stockholm: connecting land, the digital and energy

Stockholm recently developed a program that orients the location of data centers, requiring the recovery of their surplus heat. Stockholm's data parks represent a major initiative in terms of mastering the energy and installation of data centers. The Stockholm Exergi company,[129] created in 2018, half owned by the city and half by Fortum initiated this project
For 2030, Stockholm Exergi's ambition is to eliminate the 10% of fossil fuels in its energy mix and replace them by heat recovery.[130] One of the specificities of the city of Stockholm is having a very efficient heating network, whose 2,800 km of network are supplied by five large heat and electricity production units[131] with a total capacity of 4,000 MW of heat and 650 MW of electricity.

Figure 34. Location of the five large energy production units.

With rising demographic growth, the objective is to increase meeting heating needs[132] while lowering CO_2 emissions. Sweden is very advanced in the development of renewable energies and recovery, and it is from this perspective that Stockholm Exergi started to reflect in 2012 on a

[129] Formerly Fortum Värme, a branch of Fortum that is one of the main Swedish energy companies (production and sale of electricity, heating and urban cooling). In thermodynamics, exergy is the maximum part of energy that can be used, it is a magnitude enabling the quality of an energy to be measured.
[130] Interview with Erik Rylander, head of Open District Heating and Stockholm Data Parks, October 31, 2018 in Stockholm.
[131] With over 10,000 buildings connected to the heating network, it represents a "heat sink" of 12 TWh.
[132] The success of heat recovery is due to the fact that the Stockholm network is the largest heating network of the Nordic countries (and the largest cooling network in the world). The coexistence of heating and cooling networks makes flexible and economical solutions possible. In this cold climate, heat has a value, and the country has over 25 years of experience in capturing and reusing surplus heat.
We can also mention heat recovery from the interconnection centers of the Stokab network, which is done in the Östra Reals school. The heat emitted from the connection is converted into the school's heating system, which makes it possible to reduce electricity consumption by 30%.

program of heat recovery from data centers. "A data center load of 10 MW can heat around 20,000 modern residential flats" asserts Erik Rylander, head of energy for the project. Without being a major interconnection hub (like Frankfurt, London, Amsterdam and Paris), Stockholm is a quality location for data center operators that can find electricity of a renewable origin, a cold climate (which reduces air-conditioning needs), favorable taxation and now an ambitious policy on heat recovery. It was in 2014 that the partnership was formed between Stockholm Exergi (then Fortum), the city of Stockholm, the Ellevio electricity operator and that of the dark fiber operator Stokab[133] in order to orient the location of data centers, requiring in return the recovery of their surplus heat. The interest is to rationalize and control their urban installations, while favoring a territorial energy efficiency.

The Stockholm Data Parks program chose to specialize four sites to house data centers (of over 5 MW), in order to control the expansion of data centers by offering them:

- Renewable energy at negotiated rates;
- Connection to the building's fiber;
- Rapid and accompanied authorizations;
- The free use of the city's cooling network when the data center is charged at over 10 MW.

In exchange for:

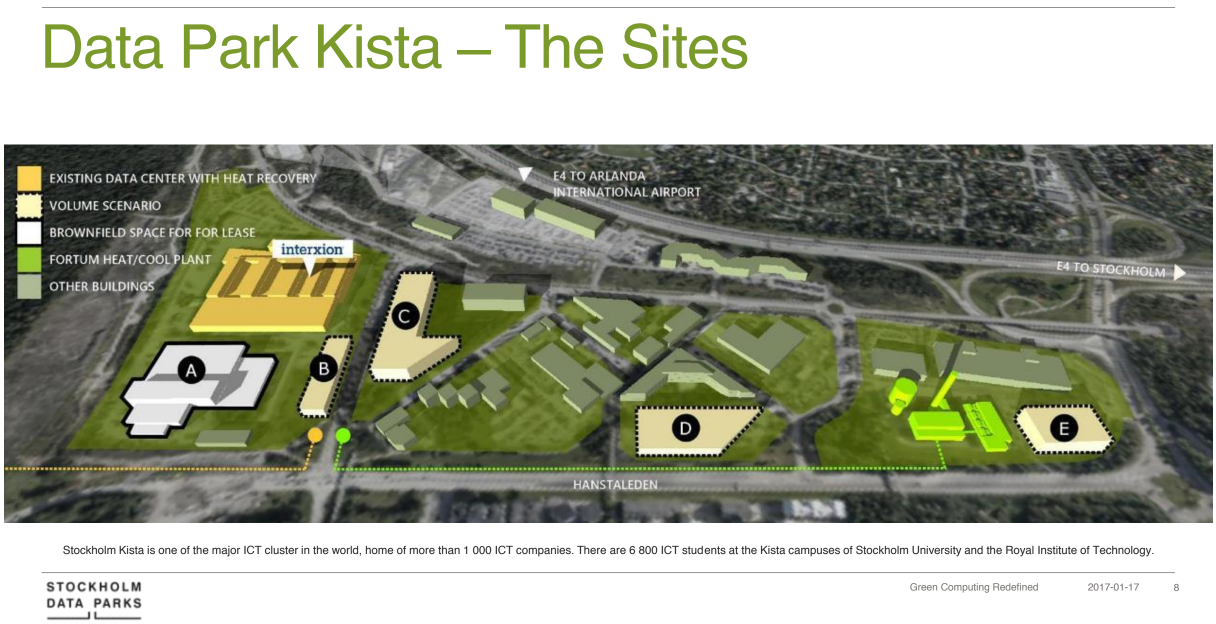
- A contribution to the local energy system via pooled heat recovery equipment also made available.

An alternative option permits the data center to manage its cooling itself. Exergi then buys the surplus heat, at a price reflecting its production costs of the alternative heat.

Stockholm wishes to position itself on the Nordic market by increasing the installation of data centers. The Stockholm Data Parks program proposes four parks of several hundred hectares specialized in housing data centers: Kista (opened in 2017), Brista (opening planned for 2018), Skarpnäck (opening planned for 2018) and Vasby (opening planned for 2019), all located on city land that cannot be rented to them unless they agree to sell their waste heat.

- The first site, in the Kista district, is located near the highway, with an Interxion site already present, a heat and cold production plant of the operator Exergi, and many car dealers whose parking lots can be mobilized to make the zone dense, but also wooded areas. An extremely large former printing plan can also be transformed.
  The heart of the Kista district, farther east, is an existing service sector, concentrating the Swedish IT sector, integrated into the city and in the immediate vicinity of residential areas and universities (Stockholm University and the Royal Institute of Technology).

[133] Stokab is a public company, a dark fiber operation, solely supplier of the physical infrastructure and not of services. It has belonged to the city of Stockholm since its creation in 1994. Its foundation resulted from the city's ambition to invest in the long-term planning of open and neutral digital infrastructures to guarantee fairer competition in services. Stokab has a very strong discourse on the idea of public service as the base of the development of services and innovation (notably for SME) consequently contributing to growth and job creation. The deployment of the network is limited to the greater Stockholm region and coverage ensures the multi-fiber FTTH connections and covering 90% of households and almost all the commercial buildings. It is one of the world's largest dark fiber networks.



- The second data park, Brista, is near the airport and extends over an unbuilt space with a visible rocky base, between a railroad track and an electricity and recycling production installation.
- Lastly, the third is located in the Skarpnäck district, a mixed-use area, in which an Equinix site is already installed not far away. The data park is a footprint wedged between two large roads, where an electricity production installation is located, an undeniable argument of attractiveness for data centers.

Under preparation for 2018

Brista, 200 000 m²

Skarpnäck, 20 000 m²

STOCKHOLM DATA PARKS

Green Computing Redefined 2017-01-17 10

At this stage, the Interxion (40 MW at Kista) and Multigrid companies are stakeholders of this data center parks project, but other corporate or colocation data centers are part of the heat recovery program (without being in the data center parks: Bahnhof (three contracts), Ericsson (two), H&M (two), ComHem, Bankgirot and GoGreenHost

For Erik Rylander, this project's success factors are:

- The robustness and size of the urban heating network;
- The number of customers for the heat (need for 12 TWh/year);
- A clear technical interface;
- The transparency of the system and the predictability of heating needs.

This strategy makes it possible to channel the future development of data centers that the city anticipates. It attempts to find the sufficient incentives to orient their installations, in existing sites, and in buildings constructed or to be constructed. It targeted sites located ahead of time by major actors like Interxion and Equinix, bringing together assets in terms of electricity supply and connectivity, by urbanizing either natural spaces contiguous to urban areas or underused spaces as in Kista, or sites with several service constraints, natural but alongside electricity production plants.
If this reinforces the model of single-function activity zones, the approach is pragmatic faced with a very rapid and opportunistic development of data centers.

6.2 Red Hook: from digital resistance to the energy micro-grid

Red Hook is a neighborhood in Brooklyn, New York, a peninsula and therefore extremely vulnerable to intense climate events and floods, with a young population with modest incomes. It has about 11,000 inhabitants, over half of whom live in low-income housing.

Figure 35. The Red Hook neighborhood in Brooklyn, New York (background: OSM).

In 2002, the Red Hook Initiative (RHI) was launched, first on public health questions for the inhabitants. This not-for-profit initiative next moved to its own building in 2010. Wanting to further reach the neighborhood's residents, it also wished to be able to create a digital community. The question of digital inclusion was therefore taken up in 2011, with the help of the Open Technology Institute and a student from the Parsons School of Design, to provide free access to the Internet via Wi-Fi, managed by the residential community, and more particularly young people looking for jobs who are trained to manage and repair the network[134]: the digital stewards. The network consequently started to distribute from the RHI building, via a Ubiquiti nano-terminal on the roof and a router in the building, connected by ethernet to the center's modem. Access to Wi-Fi also provided access to the RHI website and a forum, to favor the involvement of the inhabitants in local projects. In March 2012, another nano-terminal was installed on the roof of a residential building to increase the network's coverage. This nano-terminal was not connected to the Internet at first, but to a GuruPlug Server, a small, low-consumption server functioning on Linux. This server then hosted a local portal of the same type as RHI. The network was therefore extremely local. It functioned via the Commotion software program that permitted the creation of Mesh networks (see specific section before). Moreover, specific digital tools for and by the community were also developed, through workshops, notably the following two applications:

- Where's the B61 Bus? – a real-time application on the locations and arrival times of the B61 bus;
- Stop & Frisk Survey – an application so that the inhabitants can provide information on their interactions with the police and improve local security.

Through the question of inclusion and Internet access, that of resilience faced with floods and electricity cutoffs was also addressed. The network moreover functioned well during Hurricane Sandy in 2012.

[134] New America Foundation 2013. "Case Study: Red Hook Initiative Wi-Fi & Tidepools," *Open Technology Institute*, February 1. Available from https://www.newamerica.org/oti/blog/case-study-red-hook-initiative-wifi-tidepools/ (consulted on October 22, 2018).

The RHI building was the local backup center, open 14 hours a day for 24 consecutive days, offering electricity, water, heating and the Internet, consequently facilitating contact for help between people. On the first few days after the storm, nearly 300 people were connected a day. The network has been extended since this event.

In 2015, an initiative carried out by other neighborhood leaders[135] to install an energy micro-network won the NYSERDA prize to carry out a feasibility study with the objective of improving the autonomy of the neighborhood faced with electricity cutoffs and the fragility of the network in Brooklyn. The idea was to collectively think about the development of an Internet micro-network and an electricity micro-grid and to see how they could interact.

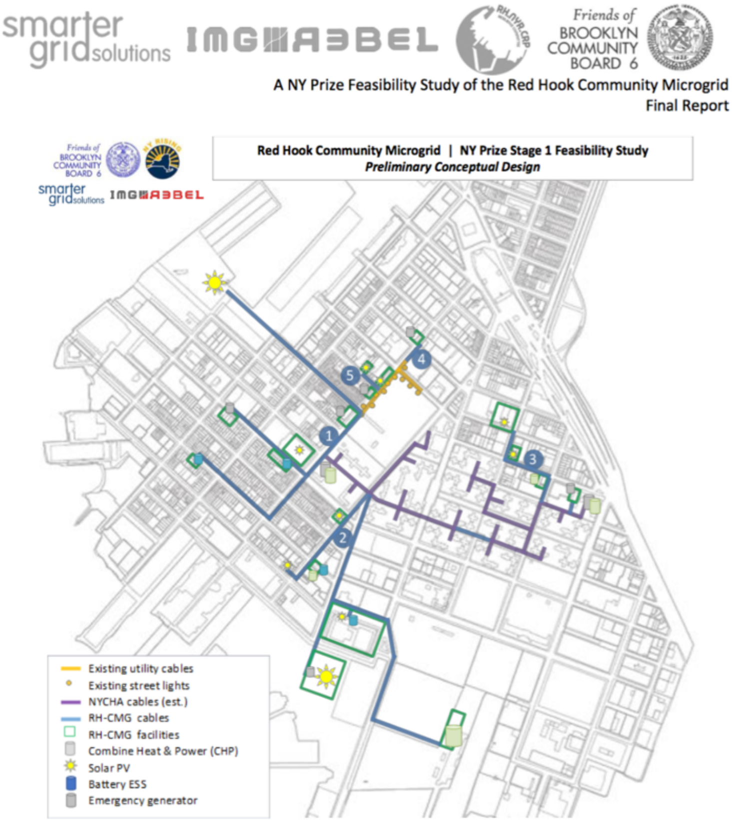


Figure 7: RH-CMG Conceptual Design

Figure 36. Red Hook Community Microgrid. (source: NYSERDA file)

The project was not chosen for phase 2 of financing by NYSERDA. It has therefore not been executed. It projected providing electricity, heat and hot water, through a gas-fired cogeneration plant, solar panels with as backup, diesel-oil and gas-fired generators, to nearly 2,800 apartments (6,300 people) of the New York City Housing Authority, but also backup sites in the event of a natural disaster: the RHI building, an Ikea store and other critical sites.

The combination of the energy micro-network and the citizen Wi-Fi, as can been seen on the map below, would have been an innovative harnessing for the neighborhood's autonomy and resilience, given the forecasts of reoccurrences of intense climate events put forward by the IPCC reports. This is all the more relevant as the micro-network itself needs an efficient and robust data communication network to function, just like the communication networks needs electricity. In the event of a cutoff of the micro-network itself, this project also planned a backup system for every RF Mesh gateway node with a solar panel and a battery system.

[135] Smarter Grid Solutions (technical engineering), IMG Rebel (consultant on financing), RH-NYR-CRP (stakeholder lead and community co-lead) and FBCB6 (community co-lead and project admin).

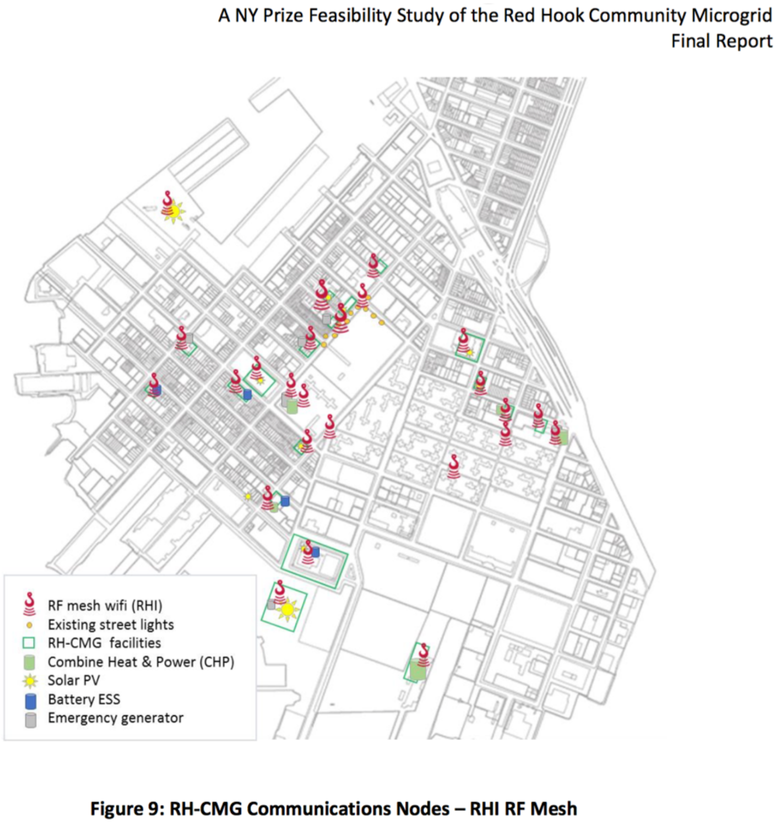


Figure 37. The gateway nodes of the Red Hook Community Microgrid. (source: NYSERDA file)

Since 2014, Red Hook Wi-Fi has moreover developed solar energy for its Mesh network, through subsidies from the New York City Economic Development Corporation via the Rise program. The NYCEDC is also helping develop five other resilient local Wi-Fi sites: in East Harlem, Hunts Point, Gowanus, Far Rockaway and Sheepshead Bay, with the support of local institutions, the participation of residents and the contribution of the Resilient Communities program of the New America think tank.[136]

Social insertion, energy and digital resilience, Internet access: the Red Hook project combines several major dimensions and proposes an interesting model for all sorts of communities.

[136] For more information: https://www.digitalequitylab.org/what-is-digital-equity-part-1/

7. An energy, digital and territorial prospective

The start of the 21st century marked the acceleration of the climate shift and environmental pollutions as well as the exhaustion of resources. This environmental disaster phenomenon is paired with an urbanization acceleration process on the worldwide scale and the digital offers new perspectives for the urban crisis and that of urban its services. For the historian of sciences Orit Halpern, "the preoccupations concerning climate change, the growing scarcity of energy sources and the collapse of security and the economy are making urban planners, investors and governments turn to intelligent infrastructures envisaged as value production sites and as a possible salvation for a world ceaselessly defined by disasters and crises."[137] It seems that the scenarios offered by the promoters of the smart city are part of a perspective that aims at pushing back crisis situations (economic, environmental, political) through the hope of a better management and anticipation of consumptions and productions and this, without however that the exhaustion of natural resources (minerals, arable land, sand, drinking water…) and various pollutions not be a lever likely to more globally redirect our impact on the "Earth system" as a certain Richard Buckminster Fuller liked to call it.

In this part of the report, in light of the major trends identified on the evolution of energy consumption in particular and the persistence of "technological solutionism," we will synthesize the alternative trends emerging toward a more low-tech and sober Internet, before looking at a prospective approach, through three possible digital worlds: growth and digital ultra-centralization; stabilization of the digital technical system and infrastructural diversity – a quest for a difficult resilience; digital ultra-decentralization – the end of data centers?

[137] Orit Halpern, "L'architecture comme machine: la ville intelligente déconstruit," in Andrew Goodhouse (dir.), *Quand le numérique marque-t-il l'architecture ?*, CCA, Stenberg Press, 2017, p.126.

7.1 Major fundamental trends identified

Climate change, exhaustion of natural resources, pollutions

"Low energy demand and low demand for land and GHG-intensive consumption goods facilitate limiting warming to as close as possible to 1.5°C."
IPCC report, October 2018, Chap. 2, p.4

<u>Climate change and risks</u>

The IPCC report published in October 2018 stresses the fact that climate change is already underway: increase in extreme climate events, disappearances of ecosystems, rise in ocean levels. France is aiming at carbon neutrality for 2050, therefore following the IPCC recommendations:
"Limiting warming to 1.5°C implies reaching net zero CO_2 emissions globally around 2050 and concurrent deep reductions in emissions of non-CO_2 forcers, particularly methane," Chap. 2, p.4

Today, the digital sector is increasing its CO_2 emissions by 8% a year (whereas it should reduce them by 5% a year[138]), and could emit as much as the automobile sector in 2025.

According to this latest IPCC report, it is possible to remain under 1.5°C of planetary temperature increase by immediately setting up ambitious transition policies, reducing CO_2 emissions – and their forcers – by half, notably by:

- **Reducing energy consumptions in every area and better energy efficiency.** The digital is moving in the opposite direction: the global energy consumption (producing equipment and making it work) of the sector was 2,000 TWh in 2013; 3,200 TWh in 2018 and forecast at 6,000 or 7,000 TWh in 2025,[139] taking into account gains in energy efficiency.

La part du Numérique dans la consommation finale d'énergie (elle-même en croissance de 1,5% par an) aura ainsi augmenté de presque 70% entre 2013 et 2020.

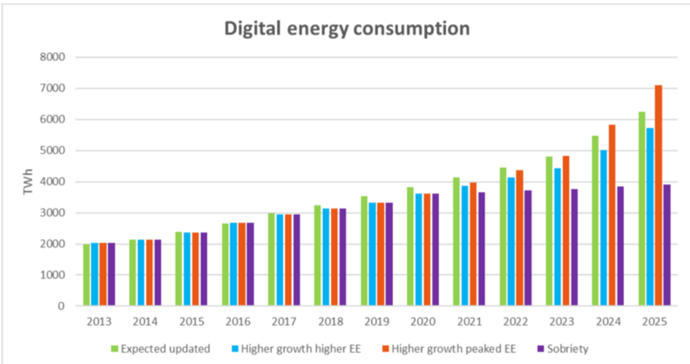


Figure 1 : Évolution 2013-2025 de la consommation énergétique du Numérique en TWh
[Source : [Lean ICT Materials] Forecast Model. Produit par The Shift Project à partir des données publiées par (Andrae & Edler, 2015)]

- **The development of renewable energies** (but also nuclear energy if it is low-carbon for certain pathways cited by the IPCC) **and the use of electricity**: some of the digital actors are turning toward the development of renewable energies in their energy mix (as seen before in the report) but this solely concerns the supply of the data centers of certain major digital actors, and remains incidental on the scale of the global carbon footprint.

- **The elimination of the use of coal, the decrease in the use of fuel oil and natural gas.** Coal is still used to produce electricity on the East Coast of the United States, which notably supplies the data centers in Loundoun county,[140] near Washington, DC. We can also mention its very

---

[138] *Lean ICT* report, The Shift Project.
[139] Idem.
[140] Loundoun county, with notably the city of Ashburn, has one of the world's highest concentrations in data centers.

widespread use in China. Most of the backup generators function on fuel and it is envisaged to replace some of them with gas-fired generators to limit air pollution. Certain projects on making the electricity supply of data centers more reliable are based on the development of gas-fired cogeneration plants (CHP), or exceptionally, biomass. Even I, in 2017, electricity produced from coal only represented 1.8% in France, the country has committed to shutting down its coal plants by 2022.

- **The protection of the ground against artificialization**. The data storage industries have not taken a position on this question. The determining factors of their installations do not take this environmental imperative into account

It must moreover be noted that extreme climate events will have impacts on digital infrastructures,[141] as of today little anticipated:

- **For the networks:**
    - Risk of sea immersion of the Internet backbones, not all equipped to resist it.
- **For the data centers:**
    - Floods and storms: integrity of the building and IT installations (example: Hurricane Sandy in New York in 2012, Hurricane Harvey in Texas in 2017);
    - Droughts and heatwaves (compared to cooling): pressure on water resources (competition of uses), growing air-conditioning therefore electricity needs;
    - Weakening of electricity networks with extreme events: increasing number of blackouts and more frequent use of backup installations.

- **In a cascade, for the territories:**
    - Aggravation of urban heat island phenomena by data centers;
    - Needs for prioritizing electricity and water needs;
    - Growing use of backup infrastructures causing air pollution (fuel) and additional CO_2 emissions (fuel and gas)

<u>Exploitation of natural resources, pollutions and social impacts</u>

Beyond the production of carbon emissions and the question of exhausting natural resources, the digital sector has negative impacts on the planet:
- Destruction of the landscape and monopolization of land (Congo, Brazil, China…) for the mining of rare earths and metals required for the production of IT terminals, but also for their dumping in landfills (Ghana, India);
- Pollution of the air and soil (China);
- Massive water consumption for mining and pollution of the phreatic layers.

A few figures cited by Guillaume Pitron in his work on rare metals[142] illustrates this: "Each year, the electronics industry consumes 320 tons of gold and 7,500 tons of silver, monopolizes 22% of worldwide consumption of mercury (514 tons) and as much as 2.5% of lead consumption. The manufacturing of computers and cellphones alone swallows up 19% of the global production of rare metals like palladium and 23% of cobalt."

The digital sector also has impacts on populations:
- Terrible work conditions of the local populations;
- No positive local economic impact of these activities (the profits are not locally reinvested).

It should be noted that digital overconsumption occurs in North America, Western Europe and Japan above all, but the environmental and social repercussions are found in Asia, Africa and South America. Geopolitical impacts accompany these phenomena and new dependencies are instituted between countries perpetuating an unequal ecological exchange and a "colonialist" relationship.

---

[141] See http://ix.cs.uoregon.edu/~ram/papers/ANRW-2018.pdf for an evaluation of the impacts of the rising water level on networks and data centers in the United States.
[142] For more details, notably see the work by Guillaume Pitron, *La guerre des métaux rares. La face cachée de la transition énergétique et numérique*, Éditions Les liens qui libèrent, 2018.

The urbanization of the world

The world's population has rather precisely followed a projected growth in the average scenario proposed by the Canadian demographer Nathan Keyfitz in the 1990s, since it should reach a maximum of 10 billion Earth-dwellers by the end of the 21st century.

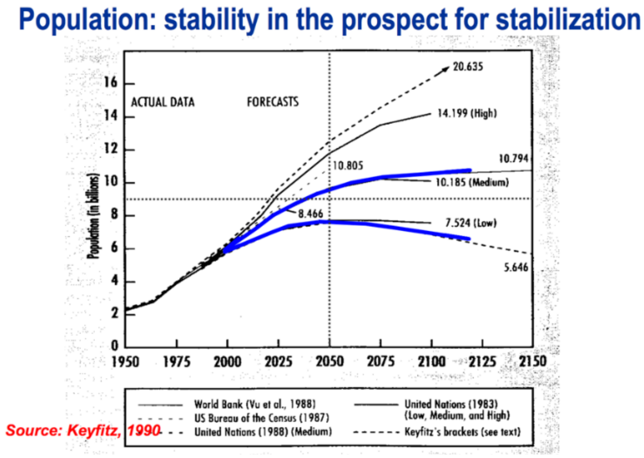


Figure 38. Projections of the world population, source: Keyfits (1990) and Criqui (2018)
https://graal.ens-lyon.fr/ejc2018/2018-11-12_EJC_Lyon_Criqui.pdf

This scenario, also proposed by the UN, is paired with a growing urbanization of the population since it will be 85% urban by 2050, a rhythm of 70 million additional urbanites each year until that year. In parallel, the UN stresses that the cities are also the territories that will suffer the most from global warming: heatwaves, floods on the coasts and inland, new epidemiological vectors, air pollution, hydric stress… This demographic growth will feed part of the growth of the digital sector, and concentrate its infrastructures in the urban territories and their contiguous outskirts.
A digital catchup effect is to be expected in countries that are not very connected today. Many of the planet's inhabitants still don't have an access to the Internet and the digital; it is estimated that nearly half of the world's population does not have an Internet access.

The persistence of "technological solutionism"

Despite its environmental impacts, the digital continues to develop at a dizzying speed. The massive Internet of Things, Big Data, autonomous vehicles connected to data centers (edge and/or Cloud) and based on artificial intelligence services and the blockchain are part of trendy scenarios.
The projections of the deployment of connected objects are hallucinatory and very variable: 35 billion objects in 2030 (Institut Idate[143]), 125 billion (IHS Markit[144]), up to the technology conglomerate Cisco Systems, Inc., which projects 500 billion objects connected to the Internet in 2030.[145] Cisco also estimates that half of all the IP network connections worldwide will be to IoT devices or M2M (machine-to-machine), usurping IP connections from laptops or smartphones.[146] These embedded electronics are furthermore an accelerated obsolescence factor of these objects and equipment.

Unfortunately, this massive digital rollout does not yet compensate for the moment for the impacts related to other sectors: the IT4Green (IT for Green). The contribution of the digital to the reduction of environmental impacts still remains to be clearly demonstrated. A study conducted for ADEME[147]

[143] Institut IDate: https://fr.idate.org/
[144] IHS Markit: https://technology.ihs.com/596542/number-of-connected-iot-devices-will-surge-to-125-billion-by-2030-ihs-markit-says
[145] Cisco Internet of Things at-a-glance: https://www.cisco.com/c/dam/en/us/products/collateral/se/internet-of-things/at-a-glance-c45-731471.pdf
[146] Cisco IoT: https://www.lemondeinformatique.fr/actualites/lire-l-iot-monte-en-puissance-avec-la-gestion-de-parcs-automobiles-73752.html
[147] Potentiel de Contribution du Numérique à la Réduction des Impacts Environnementaux: https://www.ademe.fr/potentiel-contribution-numerique-a-reduction-impacts-environnementaux

notably made possible after an in-depth bibliographical review on the state of the art to observe a great heterogeneity between the different documents studied, a large disparity in the methodologies chosen and numerous weaknesses that comprise genuine curbs on the consolidation of the data and scientific results.

Jonathan Koomey, a researcher at Stanford University and a internationally known specialist in the energy impact of the digital, asserts that inflationist and technologically isolationist discourses were able, in the past, to lead to harmful infrastructural oversizing. He notably cites the massive overinvestment in optical fiber in the United States, based on a false figure, repeated without ever being verified, in the second half of the 1990s, and that precipitated infrastructural obsolescence.[148] The multiplicity of figures that feed forecasts are often very questionable, even just plain bullshit (BS) Jonathan Koomey tells us, asserting: “In fast-changing fields, like information technology, BS refutations lag BS production more strongly than in fields with less rapid change.”[149] The refutation of erroneous data is always complex and belated vis-à-vis the announcement effects of these same data notably in the field of the prospective of information technologies in which changes are very rapid.

The dominant narrative of the smart city is today a matter of an approach that bases the solving of complex urban problems almost entirely on information and communication technologies: mobilities, air pollution, water or electricity network management… This technical and computational approach also seems to be one of the main tools of the neo-liberalization process of the cities,[150] through the shift of the control of urban data from the public authorities to digital companies that participate in and exploit the data that they work toward producing for commercial purposes.

Big Tech’s visions of the future far from shifting the global “Capitalocene” trend[151] to an adaptation of humans’ ecological footprint to the charge capacity of the planet[152] continues a perspective marked by the seal of technological solutionism. However, urban and special narratives exist that are alternatives to the smart city and are spreading in which information and communication technologies convey more techno-critical visions. They are low-tech, distributed, respect freedoms, are eco-responsible and consider the degrowth of the informational and communicational city, sometimes at the limit of fiction and utopia, to envisage in another way the links between the digital, the city and the territory.

7.2 Emerging trends

Movements of citizen reappropriation and relocation of network infrastructures

A deep economic, technical and social movement emerged in the early 2000s. For the urban utility networks, notably water and electricity, alternatives to the historical centralization model took the form of smaller-scale production plants and networks (very different from those of the beginning of the history of electrification) and met challenges aiming, in most cases, at promoting a diversified and low-carbon energy mix, and sometimes a more local and democratic governance, as well as more sober behaviors that aimed at degrowth. The economist Jean-Claude Berthélemy transposed the analysis of commons to decentralized electricity networks. He showed that the growing interest in the relocation of productions and micro-grids can be “interpreted as an example of the application of the ideas developed by Elinor Ostrom on the contribution of polycentric governance modes in the solving of the tragedy of commons (Berthélemy 2016: 85-106).”

For the digital, initiatives in favor of a more decentralized management have always existed, and have been developing these last few years.

[148] http://www.koomey.com/post/179556571967
[149] idem.
[150] Evgeny Morozov and Francesca Bria, *Rethinking the Smart City, Democratizing Urban Technology*, Rosa Luxemburg Stiftung, report, New York, 2018.
[151] Jason W. Moore (dir.), *Anthropocene or Capitalocene?: Nature, History, and the Crisis of Capitalism*, PM Press, 2016.
[152] Tim Jackson, *Prosperity without Growth: Economics for a Finite Planet*, Routledge, 2009.

Concerning the distributed digital micro-networks, heterogeneity and infrastructural diversity dominate in terms of:

- Interconnection;
- Governance
- Technical functioning (hardware, software).

In the family of large or macro-technical systems (LTS), the fiber network is very different from the electricity network that is much more centralized and benefited from a deployment on the totality of the territory, as a public service right after World War II. The history of the telecom networks and the installation of fiber in the late 2000s did not favor a deployment that was as large, egalitarian and controlled. Many telecom companies installed their infrastructures: fiber and dark fiber depending on the market's profitability (favoring large metropolises, to the detriment of rural territories and other "white" zones).

The large digital technical system thinks of interconnection in a very centralized manner (interconnection is that of the major operators). In a different way, the distributed networks rely on the network's moderators or users. They are the ones that make the technical system, whose scope is extendable, evolve.

As for electricity, there are two opposing ideologies. On one hand, the defenders of the historic network advocate the integration of renewable energies into the existing technical system, through the smart grid in a macro-infrastructural technological and cultural continuity. On the other, a change in paradigm and a technological and social breakthrough is emerging through the experimentation of new technical systems, the most distributed and independent possible from the existing large electricity networks.[153]
For the digital, the idea is to envisage clusters of distributed and interconnected digital micro-networks, insofar as the data are produced and shared by the users. It is a question of creating parallel, more neutral networks without filters on which personal data are protected. In this case, each unit must maximize its capacities in terms of connection, management, content and storage, to ensure functional autonomy. Moreover, the energy self-sufficiency of the alternative digital networks is a subject that is still very little documented, the majority being connected to traditional electricity networks, excepting a few small-scale experiments.

It should furthermore be noted that the small scale does not suffice to build a sustainable socio-technical alternative (robust technology, no GHG emissions, decrease in consumptions). As a result, the electricity like digital micro-networks are not necessarily low-tech, following the example of the blockchain.

A low-tech Internet

The idea of low-tech was notably developed by Philippe Bihouix in his work *L'âge des low-techs*.[154] This idea covers several dimensions:

- Identifying the most sober techniques in consumption and gray energy and adapted to needs;
- Favoring reparable, recyclable, modifiable technologies;
- Developing ecosystem approaches.

Thinking on low-tech Internet requires several elements: building the equipment, repairing it, making it consume less energy from one end of the line to the other, recycling it…

- The GreenTouch project (see before in the report) proved that it was possible to make an Internet function that consumed 1,000 times less energy by activating eco-design levers, including fighting against "bloatware" (software that consumes an increasing amount of resources),[155] energy efficiency concerning the networks and terminals as well as the data centers. Services like Greenspector for example help design lower energy consumption applications that use batteries less.

[153] Fanny Lopez, *L'ordre électrique, infrastructures énergétiques et territoires,* Éditions Metiss Press, 2019.
[154] https://entreprisecontributive.blog/2018/01/07/osons-une-innovation-low-tech-sobre-et-resiliente-par-philippe-bihouix/
[155] https://interstices.info/le-syndrome-de-lobesiciel-des-applications-energivores/

- Kris de Decker, editor of the *Low-tech Magazine* site, has successfully tested the feasibility of a low-tech Internet site[156] while first thinking of a lower energy consumption web design with static pages (the site updates once a day, and the new comments appear), compressed images but also a house hosting on a server supplied by solar energy paired with a simple storage battery. The fab lab, hackerspace, recycling center and repair café movements also favor the repair and reconditioning of computer equipment.

Digital sovereignty, defense of private life: growing tensions around data

The location, access, processing and protection of digital data are highly political subjects for governments that wish to protect their national interests as well as for citizens who want to protect their private life and freedoms. These two interests can be contradictory in the case when the government spies on its own citizens. The recent scandals on the possible intervention of Russia in the American elections, or the Facebook/Cambridge Analytica scandal are recent emergences of this dual issue.

In 2015, Russia for example forced foreign organizations to store the personal data of Russian citizens on Russian territory.[157] While Google and Apple complied, Linkedin resisted and was subsequently banished from the country. Other countries are attempting to do the same. This involves either hosting in the existing data centers on the territory or building their own.

in Europe, the General Data Protection Regulation (GDPR) provides a framework for data management, without causing at this stage a growth in new data centers. Moreover, a Big Tech backlash trend is emerging in Europe on political levels with Margrethe Vestager,[158] European commissioner on competition, as well as on the level of civil society with, for example, the Quadrature du Net campaign to “de-Google-ize the Internet.”

These different dimensions of data processing and storage are complex and their impacts are difficult to anticipate, but they are in a position to influence the geography of data centers in the future.

[156] https://solar.lowtechmagazine.com/2018/09/how-to-build-a-lowtech-website.html
[157] The Russian federal law of July 21, 2014 N 242-FZ on “the changes made to certain legislative acts of the Russian Federation specifying the modalities of processing personal data on information and telecommunications networks.”
[158] http://europa.eu/rapid/press-release_STATEMENT-17-1806_en.htm

7.3 Prospective: three possible digital worlds

The reflections, debates and international regulations on the digital give rise to a rather centralizing perspective from which scenario 1 extrapolates the trajectory even if different trends can continue to coexist in scenario 2. Unlike scenario 1, scenario 3 marks a radical break. All the scenarios are based on prospective figures mentioned in the report.

Scenario 1: digital growth and ultra-centralization

This is a scenario that marks the monopolistic reinforcement of Big Tech, the large companies of the digital, and that is going to see Internet traffic multiply: 100 billion connected objects for 2030 (IoT), an increase in storage needs and correlatively electricity needs for the digital sector, consuming as predicted 51% of worldwide electricity in 2030.

An increasingly centralized, secure and controlled Internet
This is the completion of the shift from the horizontal model to the vertical, of the "bazaar to the cathedral" system. The architecture of the Internet becomes a group of networks dominated by ends linked to the financialization of exchanges, the "platformization" of services, surveillance and cybersecurity. The increase in filter systems marks the end of Net neutrality. Its margins are criminalized.
The proprietary architecture model prevails, the networks support machines of an increasingly small number of constructors for better control of flows.[159] This is the reinforcement of the vision of the Internet as an information highway on which a technical and economic model favoring relations between customers and powerful monopolistic servers dominates.
The governance of the Internet is left in the hands of private economic actors with strong lobbying by Big Tech that maintains financial pressure on politicians with the strengthening of the existing monopolies, notably on data. This growth logic favors the centralization and consolidation of the market around GAFAM and BATX whose capitalistic power dominates and fabricates the offering. As there are very few actors of intermediate size, the colocation market has also consolidated around a dozen actors worldwide.

LTS spatiality or the victory of the information highway
The digital technical system follows the logic of large technical systems (LTS[160]), and there is historically a correlation between the large scale, the savings it permits and centralization. With the growth of the Cloud, largely in the hands of GAFAM, two phenomena are expected. First, the multiplication of very large-scale data centers, while developing a reticular system combining objects on smaller scales (colocation or not), but also edge computing.
The Big Tech companies have become major actors in urban planning and development with the multiplication of connected urban districts. If Google's urban planning subsidiary, Sidewalk Labs, was one of the first with the creation of the Quayside district in Toronto in 2020, GAFAM have strongly invested in real-estate markets and urban management, notably on public spaces and sidewalks. The same is true for energy production: Google, Facebook and Microsoft became involved in energy production and distribution, becoming major actors in the sector with the development of large-scale solar and wind farms. They have also specialized in the sale of micro-grid solutions and have become major actors in the development of individual and collective self-consumption (notably in the United States, but also in Europe).
From a territorial viewpoint, certain rural zones were dedicated to housing very large data centers (following the example of the farm with 1,000 cows) with in the vicinity the development of renewable energy or biomass plants like ezCloud (a cloud computing project that uses the methane produced by cows). New agro-digital territories have emerged with the systematization and recovery of heat for

[159] Francesca Musiani and Valérie Schafer Métropolis, "Le modèle internet en question (années 1970-2010)," in *Flux*, 2011/3 no. 85-86, pp. 62-71.
[160] Joerges Bernward, "Large Technical Systems: Concepts and Issues," in Hugues T. P., Mayntz R. (dir.), *The Development of Large Technical Systems,* Frankfurt, Campus Verlag, 1998, pp. 9-32.

greenhouses, notably in the Centre-Val-de-Loire, Bretagne and Grand Est regions where climate norms for heat have remained below 35°C.
In metropolises and dense urban centers, vertical data centers or micro-data centers are inserted in numerous urban infills, as well as in traditional real-estate programs (housing, businesses, service, cultural) in order to meet the needs of the IoT (weak latencies, permanent relays). In the Île-de-France, the Société du Grand Paris has notably favored the creation of 26 data centers in the new metro stations (buried, semi-buried). Data centers have also been housed in many vacant building in the outer suburbs: deserted shopping centers, obsolete activity zones, empty offices.

Energy: the headlong rush
This scenario marks the victory of the green growth ideology and the large technical systems vision. This means: the large scale; a specific development mechanism favoring their growth; a large quantity of fossil or nuclear energies consumed; the maintenance of the unequal ecological exchange (mining of rare earths and manufacturing in countries where labor laws and environmental regulations are weak or inexistent); the production of large amounts of CO_2 emissions or end waste; the complexity of groups and subgroups functioning in a network, often opaque and managed by experts in a very centralized manner; flow control and regulation in real time. Correlated with the growth of the thermo-industrial society, macro-systems ensure the technical and cultural permanence of infrastructural entities that are the foundation of the expansion of large international economic powers. There are economies of scale and financial economies but not energy economy, no decrease in global consumption has been observed for this sector despite the heavy use of renewable energies. Among the rebound effects, we can observe a global increase in the sector's electricity consumption and CO_2 emissions. This scenario marks the failure of the control of CO_2 emissions and an increase in the planet's temperature of about +2.5°C in 2050.[161] In urban zones, we can observe large heat peaks and strong increases in consumption and in electricity voltages on the low and medium-voltage networks.

Scenario 2: Stabilization of the digital technical system and infrastructural diversity: quest for a difficult resilience

In this scenario, the digital technical system aims at stabilizing and controlling its consumptions with the development of an infrastructural diversity favoring a two-tier digital development, on one hand, Big Tech and, on the other, smaller-scale infrastructures that are more collaborative, often backed by public investments.

A more hybrid and distributed network architecture
The digital technical system is diversifying in terms of network architectures, infrastructures and contents. It admits more heterogeneity, coexistence and hybridizations. Just like China and Russia[162] have developed their own Web services and applications (with the aim of domestic control and national sovereignty) alongside the World Wide Web, Alternet proposes services that are alternatives to Big Tech, notably via Framasoft in France, unlike the censorship aim of the Russian and Chinese systems, but from the angle of local and citizen sovereignty on a free and open Internet.
Following the debates on the exponential consumption of the bandwidth and the energy effects of the digital, a Europe-wide and national regulation was passed in favor of taxing "Net guzzlers." It resulted in reducing the weight of the videos and photos exchanged, Internet sites and ads on one hand, and favors local transmission of data through the growing use of peer-to-peer systems, between users, but also more data storage on user terminals (computers) instead of constantly storing them on the Cloud (example: Spotify, Deezer), which reduces in passing the peering costs of the ISP.
We also can see the emergence of a data treatment and storage national public actor, decentralized in the regions, to limit the monopolistic abuses of a handful of private actors.

More diverse and better integrated data centers
In this scenario, there is a decrease in the development of data centers, notably the very large ones (hyperscale) in the rural zone because their electricity consumption is too high, their land and soil impact too heavy and energy pooling difficult. There is also the question of climate and terrorist risks that favors

[161] The increase in annual greenhouse gas emissions (GHG) has been continuous. In 2025, the world will have emitted nearly 6% more GHG than in 2005. See: https://theshiftproject.org/wp-content/uploads/2017/12/note_danalyse_les_indc_et_le_budget_carbone_the_shift_project_0.pdf
[162] For more information on Runet: https://www.monde-diplomatique.fr/2017/08/LIMONIER/57798

the search for a smaller-scale resilience and redundancy. Small data centers have multiplied everywhere because the quality of the network permits it, and their spatial integration is easier on this scale. These data centers sometimes become digital mediation places, for learning about Internet resources and contents as well as its technical functioning and infrastructures. The users' tolerance for breakdowns is greater because they understand the reasons for them and their implications. Information campaigns on public health issues about the dangers of ultra-connection and the negative rebound effects of the digital on the economy (destruction of jobs, desocialization, outsourcing of benefits) have borne their fruit.

Governance is more local and the municipalities, the public intercommunal cooperation structures and the regions are largely spared this data storage and processing industry, and these possible contributions for the local energy systems (with shared biomass plants, heat recovery, etc.). This ecosystem concern favored new types of hybrid equipment: fab labs, third places with collective data storage and computing spaces combined with the dynamics of wireless community networks and energy micro-network spaces (as in Red Hook), notably in rural territories where connection was weak. Data centers have become the new nerve centers of the territories. In urban zones, the decrease in logistics activities (to the benefit of the more national, local and circular economy, but also due to the drastic drop in international exchanges following the financial crisis in 2021) favored a return of business to the city and the continuous suburbs. Many peri-urban commercial and activity zones became obsolete and were transformed into digital activity zones.

We can observe a digital development that follows two logics. The first is structured around local administrations that have taken back control – since the decentralization laws of 2022 – on this common – the digital (like the energy communities and cooperatives). In an approach that combines data sovereignty and ecosystem concern, a transfer of the data center sector's wealth to the local economy (production, service, maintenance) as well as energy savings and a search for sobriety, has occurred. The second logic follows the peer-to-peer model and a topology of the pre-commercial Internet, in which Internet user communities that develop alternatives to the giants of online search and sharing (decentralized social networks, P2P research engine and content) are flourishing again. But the model is very fragile because if the P2P models exist and some storage has been relocated, the major actors of the IT market have kept control, despite the crisis, and continue to set their own conditions (notably on the Cloud). The large companies continue to call, in the majority of case, on the powerful industrialists that dominate the market on the international scale on computing, information storage and traffic management. The equilibrium of the coexistence of public actors, of the common and private, as well as the local/global relationship remains very fragile and favors the development of two Internets.

Energy: electricity degrowth, a fragile control but ambitious public policies

The digital sector was forced to decrease its CO_2 emissions by 8% a year[163] between 2025 and 2050, that is, return to the global energy consumption (producing the facilities and operating them) of the sector in 2013, which was 2,000 TWh (for 3,200 TWh in 2018 and 7,000 TWh projected in 2025[164]).

Regulations made it possible to restrict traffic that heavily consumes bandwidths by limiting certain uses and taxing those who propose them. A whole section of services (e-mail, blogs, navigation, social media) became much more economical and equipment obsolescence heavily penalized.

The locations of data centers are now defined in coherence with the Territorial Climate, Air and Energy Plans (PCAET) that henceforth included digital dimensions as well as with local "land, urbanism and energy" plans that orient the installation of data centers according to the transformation potentials of the territories, heat recovery and connectivity. The interest is to rationalize and control their urban installations, while favoring territorial energy efficiency. Moreover, the energy installations of data centers are systematically pooled with other programs.

Scenario 3: digital ultra-decentralization: the end of data centers?

It would concern building a local and intermittent Internet. When energy is available, the Internet is active. It is a sort of IT survivalism and low-tech that would be put in place in a collapse scenario. It is the return to the founding principles of the Internet (horizontal and distributed) functioning for the most part on the goodwill of communities of interest, paired with a low-tech technical approach in the context of a very advanced climate shift.

[163] *Lean ICT* report, The Shift Project, op. cit.
[164] Idem.

An intermittent Internet architecture

Wi-Fi could be developed over longer distances, going as far as 100 km.[165] This network would permit users to communicate with each other and consult websites configured on local servers.[166] Delay or disruption tolerant networks (DTN) would also be developed. They would consequently support cutoffs and very long latencies. Unlike the always active model of traditional networks, these DTN are based on asynchronous communication and intermittent connectivity.[167] They overcome the intermittent connectivity and long delay problems by using differed message switching. The information is transferred from a storage location on a node to a storage location on another node, along a path that finally reaches its destination.[168] These networks are notably used for space communication. Based on the principles of mules and autonomous messages (bundles), they are based on equipment with large storage capacities to ensure the routing of data despite network cutoffs. Different deployments were proposed for animal surveillance (zebranet network) or providing Internet access to populations far from network infrastructures via mobile equipment (snowmobiles, networks of buses or letter carriers on motorcycles). Consequently transportation infrastructure can replace a wireless Internet link. The Daknet, Saami, DieselNet and KioskNet networks, for example, use transportation equipment (buses, motorcycles) as data mules in many villages and cities without network connectivity. Each “mule” vehicle is equipped with a computer, a storage peripheral, a mobile Wi-Fi node, and a fixed Wi-Fi node is installed in each village. The e-mails sent or Web page requests are stored on the village’s local computers until the arrival of the bus or motorcycles that transmit the incoming or outgoing data.

These networks with a delay tolerance can function with an intermittent energy supply and combine well with renewable energy sources: solar panels or wind turbines can only supply the network nodes when the sun shines or the wind blows, thus eliminating the need for energy storage.

A large number of Internet application could be adapted to intermittent networks such as e-mail, filling in electronic forms, blog software, Web navigation, interaction with e-commerce sites, downloading of files (even voluminous ones) or social media.

Real-time applications such as Internet telephony, continuous multimedia broadcasting, live discussions or videoconferences are impossible to adapt to intermittent networks, which only supply asynchronous communication. A good number of these applications could be organized in different ways. Voice conversations and real-time videos will not function but it is perfectly possible to send and receive voice mail and videos. And even if continuous multimedia broadcasting is not possible, music albums and videos can be downloaded. Furthermore, these files could be “transmitted” by the lowest possible Internet technology: a sneakernet. In a sneakernet network, digital data are transmitted “wirelessly” by using a storage support like a hard drive, flash drive, flash card, CD or DVD. Before the Internet arrived, all computer files were exchanged via sneakernet, by using a strip or disk as a storage support.

An online-offline hybrid application system such as this would remain a very powerful communication network. Even if we envisaged a catastrophic scenario in which the large Internet infrastructure disintegrated, isolated low-tech networks would remain very useful local and regional communication technologies. Moreover, they could obtain content from other remote networks through the exchange of portable storage supports. It seems that the Internet can also be as unsophisticated as possible or as sophisticated as we can permit it to be for us.

Spatiality: micro-scale and long-distance

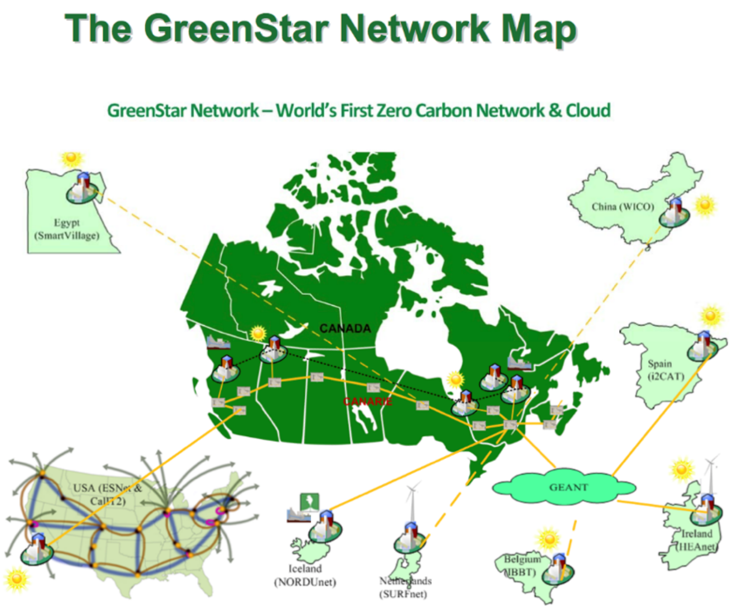
There are more low-tech small-scale servers and machines located at users and everywhere where this is possible gateway or connection nodes. This is a radical change in scale with the multiplication of distributed, light and mobile micro-infrastructures to handle connection relays with long-distance Wi-Fi systems or data mules. Many vehicles have been invented, combining energy autonomy and digital equipment and car-sharing.

[165] Through modifications of the message authentication code (MAC) layer in the network protocol and the use of amplifiers and directive antennas. The longest unamplified Wi-Fi link is a point-to-point wireless connection of 384 km between Pico El Águila and Platillón in Venezuela, created a few years ago.
[166] For a connection to the Internet, a wide-area Wi-Fi network must be connected to a “connection node” or a “gateway node” of the Internet (DSL, fiber or satellite).
[167] These networks have their own specialized protocols, superimposed on lower protocols and do not use the transmission control protocol (TCP).
[168] Unlike traditional Internet routers that only store incoming packets for a few milliseconds on memory chips, the nodes of a network with a delay tolerance have persistent storage (like hard drives) that can contain information for long periods.

The trajectory of mule vehicles strengthens local commercial linearities, intensifies the occupancy of public spaces during their passage, as well as the development of digital third places, Internet reception and repair, sociability and workplaces.
Unconnected time would favor IRL (in real life) exchanges and the development of agoras, discussion, activity and conviviality venues.
Large data centers have become obsolete warehouses, but the equipment was moved and reused for small-scale and better integrated storage.

Decrease in consumptions and majority renewable energies: follow the wind/follow the sun

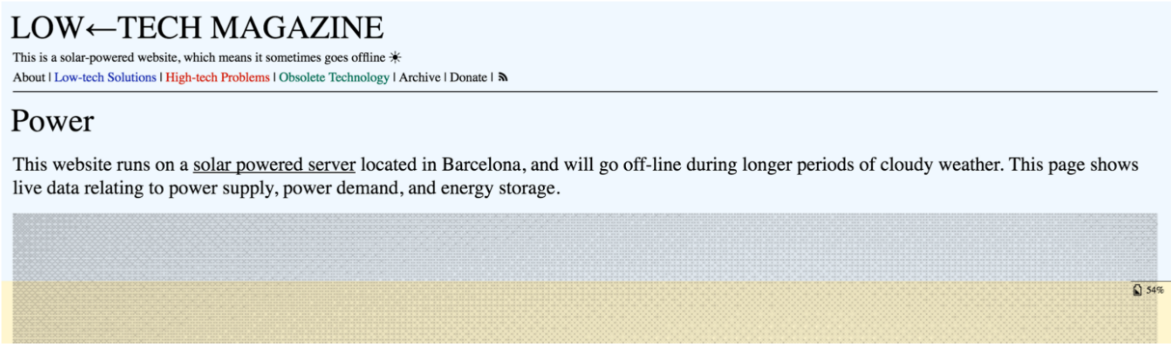
This scenario would be based on a totally peer-to-peer – mobile – model based on the IoT with a hosting function. The terminals host services for their users and deliver services to neighboring users in the "degraded" mode. Local digital service then become the norm, international services become the exception. Governments and especially communities of Internet users take control over their services. Certain aspects were explored in Canada with the GreenStar project in 2010 – using the "follow the wind/follow the sun"[169] principle. The GreenStar project thus deploys a network that functions solely on renewable energies by accepting intermittences on the network.[170]



As a preamble, this Canadian project cites a report by the government of the United Kingdom titled: *How climate change could ruin the internet.* In this text, the secretary of state for the environment, Caroline Spelman, stressed that the rise in temperatures and the climate shift were going to have a strong effect on the reliability of digital networks but also on energy distribution (closing of nuclear plants because cooling water could be too warm, less hydroelectric production due to droughts, etc.). In a collapse scenario, the reconfiguration and functioning of the digital technical system would be radically different.

The Internet as we know it, ever faster and mobile, is the product of an abundant and growing energy supply and a robust electricity infrastructure. It cannot survive if conditions change. This is what Kris De Decker[171] shows in his article: "How to Build a Low-tech Internet." Consequently the server of the *Low-tech Magazine* site created by Kris De Decker functions on an architecture based on a low-consumption processor supplied by a battery recharged by a solar panel. If the available energy is insufficient, the website is inaccessible.

[169] http://green-broadband.blogspot.com/2011/02/design-principles-for-building-networks.html
[170] http://green-broadband.blogspot.com/2011/02/design-principles-for-building-networks.html
[171] https://solar.lowtechmagazine.com/2015/10/how-to-build-a-low-tech-internet.html


LOW←TECH MAGAZINE
This is a solar-powered website, which means it sometimes goes offline ☀
About | Low-tech Solutions | High-tech Problems | Obsolete Technology | Archive | Donate |
Power
This website runs on a solar powered server located in Barcelona, and will go off-line during longer periods of cloudy weather. This page shows live data relating to power supply, power demand, and energy storage.
54%

8. Recommendations for France

8.1 Recommendations on governance and actors

Creating a "territory, energy, digital" forum

Faced with the complexity of the data center question, the evolution speed of the digital sector, the weak acculturation of the territories and local administrations on the subject and the development perspectives of data centers in France in the years to come, it seems indispensable to us to create a circle of exchanges and discussions between public actors, actors in development, urban planning and energy and data center operators and managers, whether they are colocation or associative hosts, GAFAM or large companies (notably via GIMELEC, France Data Center and the AGIT) or academic researchers.

A multidisciplinary work forum such as this can be launched at a founding event that lays the bases of functioning and the work themes to be deepened between actors.

An initial co-steering of the approach by the government seems relevant to us through the ADEME and the PUCA (Urbanism Construction Architecture Plan) for example, to provide a tone for reflections on energy and development, with support from an EcoInfo group of researchers specialized in the link between the digital and the environment.

A certain number of detailed recommendation described below can now be proposed for discussion on this forum.

Enriching the digital ecosystem with alternative hosts and ISP

Even if the colocation market, as access to the Internet, is dominated today by a few major actors, it seems however important to us to provide a place for associative and cooperative actors of the Internet, notably for the territories today both those not as well served as those that lack digital competencies and the social link. Making a place for them in the French digital landscape could make it possible to develop more local, better informed digital management and, above all, created by its own users, which could favor more sober, more economical practices in this way adjusted to needs. The examples developed above clearly show that there are many challenges, technical as well as economic and social, and the strong points of alternative digital infrastructure development are numerous, the first of them being resilience faced with climate events, the other having been already detailed.

The associative, citizen and cooperative hosts and ISP thus lay claim to a place in the French digital and telecom ecosystem to supply a neutral, open and efficient Internet to the territories, notably in those where the announcement of optical fiber has frozen investments on copper and lowered the quality of service and connection.

- The associative and cooperative ISP do not have access today to the fiber of the major operators, financed however by public funds according to the territories. They have asked, via the French Data Network federation,[172] for the creation of offerings activated for small operators in the RIP (Networks of Public Interest) and with Orange. The Chaize amendment to the Elan law thus proposed that in the absence of the supply of activated access, any operator using electronic communications infrastructures (of optical fiber) granted reasonable requests for activated access to this network coming from other operators, with the aim of proposing the best possible coverage for the end user. This amendment (article 64c) aimed at accelerating the rollout of fiber on the territory by permitting small operators to more easily access these infrastructures, in the case where these networks benefit from public subsidies. The government did not accept this.

[172] See the open letter of January 1, 2018: https://www.ffdn.org/fr/article/2018-10-21/lettre-ouverte-sebastien-soriano-et-stephane-richard

- On citizen Wi-Fi, the obligation to secure oneself the sharing of one's Wi-Fi represents a major curb for sharing connection although this can be a strong vector of digital inclusion. On one hand, the Internet user making his or her connection available must keep traces of his or her "guests" and, on the other, the HADOPI 2 law forces the user to secure his or her connection, under penalty of a fine or cutoff.

- Lastly, for the operators that develop a Wi-Fi offering, questions are asked on the future availability of Wi-Fi frequencies that could rapidly be saturated by the foreseeable growth of the IoT that also functions with the Mesh technology. One track would be the opening of "whitespaces" (unused radio frequencies) by also creating a place for citizen and associative operators.

Supporting citizen and cooperative networks is also supporting associative, decentralized and potentially more frugal hosting, favoring local social and economic development and permitting greater climate resilience for the territories.

Launching a call for projects for experimentation territories

In the white paper "Numérique et Environnement" created by the IDDRI, the FING and WWF,[173] tracks 3 and 4 propose making possible "digital and ecological experimentation territories" (we have added "energy"), which seem interesting to us from the angle of testing the impacts of a "relocated" and more sober Internet in poorly served territories or those suffering from digital exclusion.

This white paper thus proposes:
"Creating – in urban as well as rural zones – digital and ecological experimentation territories to welcome innovators who wish to test their solutions and closely collaborate with the public authorities, and ensure the sharing of experience between these territories. The large-ambition innovation territories, the positive energy territories or those that will sign ecological transition contracts with the government could welcome such projects. These territories should also multiply incubators, calls for projects and more generally systems of support for innovation at the crossroad of digital and ecological transitions."

In the spirit of "permits to do" (LCAP law, 2016) and "permits to experiment" (Elan law, 2018) for architecture and construction, certain territories or public intercommunal cooperation structures could apply to a call for projects joined with the Digital Agency (secretariat of state for the digital) and the ADEME to implement mediation and infrastructural digital learning (network and hosting) projects making it possible to both train people in the digital professions (like the digital stewards in Detroit and New York), provide a better connection and better service locally, while taking the environmental impact into account: reductions in electricity reduction, use of renewable energies, repair and reuse of IT equipment, low land footprint, connection with urban heating networks…

Creating a public service for the digital and public data centers

Today, there are local public companies (SPL) for the development of high-speed broadband in France like the SPL Nouvelles Aquitaine THD and Bourgogne France Comté Numérique for example. There are also joint municipal authorities to roll out public initiative networks (RIP). The SIPPEREC consequently developed several RIP in the Île-de-France like THD Europe Essonne and Irisé.

On the other hand, no public or public-private structure of this type proposes infrastructures or data storage services for public actors, civil society and citizens. However, a need for pooling, sovereignty, proximity and integration in local land and energy strategies is emerging.

The question is therefore acting on the competencies and structuring of the actors in the territories: favoring the emergence of intermediate actors, possibly in the form of an SPL, in the territories, offering

[173] https://www.wwf.fr/sites/default/files/doc-2018-03/180319_livre_blanc_numerique_environnement.pdf

technical assistance services on one hand, improving the spatial and energy integration of data centers in the territories and, on the other, developing and managing public data storage and processing facilities that are pooled between actors. Certain of the development SPL could take these new missions in charge, to better integrate the data center issue into development projects, their public facility projects, but also in the support of the development of digital third places welcoming small data centers of proximity.

8.2 Urban planning/environment recommendations

Favoring urban and building recycling to the maximum

As the IPCC report cited above stresses:

“In 2014, the buildings sector accounted for 31% of total global final-energy use, 54% of final-electricity demand, and 8% of energy-related CO_2 emissions (excluding indirect emission due to electricity). When upstream electricity generation is taken into account, buildings were responsible for 23% of global energy-related CO_2 emissions, with one-third of those from direct fossil fuel consumption.” (IEA, 2017a)

Minimizing the impact of building construction in terms of CO_2 emission but also the imperative to stop the artificialization of land in France encourage favoring the transformation of existing building and the recycling of the city on itself to the maximum. This is also valid for data centers.

The idea is therefore to identify all the unused industrial zones or vacant building adapted to a transformation that could house new data center areas:

- Shopping centers or commercial spaces in decline or unused;[174]
- Peaking power plants closed in Porcheville and Vitry-sur-Seine;
- Former vacant telecom buildings (those of Orange seem interesting);
- Office buildings (according to the Observatoire Régional de l’Immobilier d’Entreprise, in 2014, there were 3,3 millions m^2 of vacant offices in the Île-de-France);
- Former industrial sites.

Local planning strategies and local urbanism plans are tools that favor these transformations. An in-depth knowledge of local assets can also guide and advise data center operators.

To undertake these approaches, the global cost will also have to be evaluated and an analysis of the life cycle of a new building, compared to the transformation of an existing building, be carried out. It is necessary to compare in terms of global cost the possibility of better energy efficiency for the new building when it is in the operating phase (a building constructed for the data center in which everything is optimized vis-à-vis this use) and the adaptation of an existing building. Which project will emit the least CO_2? The same issue is raised for the renewal of IT equipment; the assessment as of today proves that the life of the equipment must be extended to the maximum but if the following generations consume less electricity.

More architecture, more hybridization

- So that new project managers emerge for the building of data centers to favor a diversification of forms, programs and new pooling (the traditional operators tending to reproduce the same objects to not disturb their economic model). Favoring executions stemming from a public-private project management for example, connected to international competitions of calls for projects.

- Encouraging research on these infrastructures, by launching, for example, financed calls for research whose commissioned agents would be architecture offices connected to the research laboratories of architecture schools or universities.

[174] The Casino supermarket chain will become involved in the transformation of a part of these stores into data centers: https://www.reuters.com/article/us-casino-data-revenue-idUSKCN1OJ1P4

- Favoring a reflection from the development milieus and architecture schools on the subject, as was already done at Science Po Paris in the framework of a partnership with the Société du Grand Paris, or the École d'architecture de la ville et des territoires in Marne-la-Vallée.

Including the data center question in spatial planning documents and territorial strategies

Data centers today are overseen on the scale of the building and on the spatial level by:

- The local urbanism plan (PLU):
  - The regulation of the zone concerned;
  - The delivery of the building permit that comprises a potential negotiation lever for the constructions, extensions;
  - The authorizations for a change in purpose for certain transformations.
- The ICPE (installations classified for environmental protection) authorizations delivered by the government, that aim at limiting potential nuisances (noise, fuel storage…) and consequently restrict the building's configuration;
- For some installations, the obligations of an operator of vital interest (OIV).

On the urban scale, no strategic document of the sustainable development and development project (PADD) or the territorial coherence scheme (SCOT) type mentions the data center phenomenon as a trend to anticipate, oversee and plan.

Ultimately, data centers are part of the territories' silent transformations.

To make these transformations visible, working toward global projects for the territories, three objectives are to be sought:

- Knowing the current situation of the data centers on one's territory: the sites, electrical power, actors…;
- Anticipating possible developments and evolutions: having a global view of the extensions to come, new projects, evolutions in the data center market…;
- Better integrating data centers into the territory:
  - Appropriate locations;
  - Architectural integration;
  - Ecosystem integration: energy, water, footprint…

Here are two tracks to meet these objectives:

a) Including the data center dimension into the PLU, SCOT, territory project approaches and crossing the energy/land/digital strategies

This implies:

- Developing knowledge of the territory's data centers through the diagnosis in the presentation reports (PLU, SCOT) and the diagnoses of the territory projects;
- Identifying the specific and strategic issues in working with the PADD and the territory project strategies;
- Meeting the data center actors to be able to jointly imagine shared actions afterward.

This work must be carried out in close cooperation with the Territorial Climate, Air and Energy Territorial Plans (PCAET), anticipating the climate risks specific to each territory (floods, droughts, susceptibility to heatwaves…) and the possible documents on the land strategy of the territories, because one of the major issues for better integration of data centers into the territories is clearly the development of crossed and connected energy/land/digital strategies.

b) Developing tools and projects

On the PLU level, the major tool will be the zoning regulation, and this to favor the formal integration of the buildings: heights, roofs, openings, inclusion of technical installations (for example, backup generators, air-conditioners), footprint, landscape integration, fences, delivery management…

The question of the number of parking places is a subject to be studied vis-à-vis the type of data center (outside clients or not?) and the number of jobs, often low. It is to also be considered regarding the possible mutations of the built environment in the future: toward a potentially more service or industrial activity? In a zone well-served by public transportation or not? Parking is an important factor as much for building the project's economics as for sealing the soil and optimizing the occupancy of the plot.

Another question to be considered is the coherence of the OIV obligations imposed by the government with the local regulations of the PLU.

Within the SCOT, the orientation and objectives document[175] defines the condition of a controlled urban development. It can include specific recommendations on the data center question, notably proposing shared tools for management and reflection, suggesting approaches, methods and partnerships. These orientation can, for example, guide the installation of data centers like those in Stockholm to favor heat recovery, land optimization, and avoid concentrations that weaken the electricity systems by locating them in the best place in terms of their criteria (connectivity, land, energy) as well as those of the territory (resilience, integration, soil management).

In the framework of these strategic approaches, it can also be envisaged designing ad hoc experimental projects that can anticipate more global strategies, or lever projects for a collective dynamic.

Anticipating the installation of hyperscale data centers and edge computing

We have observed that data centers arrived, most of the time, without the public administration being able to anticipate their installation. On one hand, the hyperscale data center phenomenon (above 10,000 m^2 of floor area) could arrive in France in the upcoming years and, on the other, the development of micro-data centers will no doubt occur with the growth to come of the IoT, 5G and driverless vehicles.

a) The very large or hyperscale data centers

The idea here is to learn from the very large data center installations in other European and North American territories: how can a balanced relationship be negotiated with these actors? How can oversizing local infrastructures be avoided? How can local electricity systems not be weakened?

What must be done, on the scale of a regional and metropolitan territory is to:

- Analyze the relevance of the location of these enormous data factories and target the territories most favorable to their installation;
- Propose installation conditions that respect the interests of the territory as well as those of the operator;
- Precisely evaluate the impacts of these installations:
    - Direct and indirect job creation and durability;
    - Local service for SME, local administration, inhabitants;
    - Impacts on land consumption, competition between land uses;
    - Impacts on the landscape and the living environment;
    - Impacts on the electricity and hydraulic system;
    - Environmental impacts (see recommendation below).

Complementary European benchmark work could be carried out (Sweden, Ireland, the Netherlands) to further contribute reflection and strategy elements, and produce a practical integration guide with a European scope.

[175] This document is the regulation of the SCOT whose prescriptions will be applied in a report on the compatibility with so-called lower rank documents and a common framework of referenced, methods and actions making it possible to work toward the implementation of the SCOT's orientations.

b) Edge computing and micro-data centers

Few actors today seem to have real visibility on this phenomenon today, however it is important to try to draw the contours of a prospective for urban territories. If these new digital installations are small (they are often compared to the size of a refrigerator), their multiplication raises questions:

- Should we anticipate dedicated technical cabinets in new buildings, more equipment in the public space?
- Will the vacant real estate of telecom operators, in particular Orange, be reused for this? Will edge data centers be installed in hyper-urban data centers, and must we therefore plan for their extensions and development?
- How can the local electricity impact of these many small units be quantified?
- Is the reinforcement of the fiber and electricity networks to be anticipated?

These are some of the many questions that can be raised to anticipate this development in the near future.

A dedicated working group could be created on this subject between local administrations, experts, urban planners, telecom operators and data centers, as well as energy operators, in order to work on joint answers (see recommendation on the creation of a forum).

Measuring and limiting the environmental impact of the “smart”

For ten or so years, the cities and territories have been developing digital strategies often grouped under the term smart city. It is fundamental to provide information on the existence and nature of what goes on behind the scenes of these projects:

- Upstream: consumption of rare earths, water and environmental and social damage in the mining countries, large amount of gray energy spent;
- Underway: energy and land consumptions;
- Downstream: electronic waste, environmental and social damage in the countries concerned by dumping and recycling.

Awareness-raising work is to be pursued on the subject, as well as an evaluation of the smart city programs of the local administrations.

a) An ecological review of the smart city and its programs

Whether the subject is mobilities, the living environment, urban projects or connected energy, we recommend taking into account – at the minimum – the need for data storage related to each program to evaluate the space and energy required for each of them for its deployment and functioning over time.

To go further, we propose following the recommendation of the FING, IDDRI and WWF in their white paper cited above (track 3-2): it concerns “undertaking – the national level and in the territories – an ‘ecological review’ of digital innovation programs, on the autonomous vehicle or the industry of the future, for example, in order to integrate the environmental issues in a non-superficial manner. The public financing of the largest project should be dependent on the existence of an evaluation of their positive and negative, direct and indirect ecological impacts.”

This would assume, beyond the land and energy impact of data storage during the project, evaluating the impacts of the three phases cited above.

b) The environmental impacts of data centers on the territories

The environmental impacts of data center projects on a territory must also be able to be evaluated on a case-by-case basis.

The question of access to data is always complex faced with operators who often cultivate secrecy. On the other hand, if the dialogue does not take place upstream, the filing of the building permit is the opportunity to have information on the project and to use it as a negotiation lever.

Simulations and extrapolations can then be carried out. We have anticipated what this tool could be, with Bastien Marsaud, an intern at the Enernum project in 2018.

IUT Lyon 1

INSTITUT UNIVERSITAIRE DE TECHNOLOGIE LYON 1
Département Informatique
43 Boulevard du 11 Novembre 1918 - 69622 Villeurbanne

RAPPORT DE STAGE - 2EME ANNÉE
DUT INFORMATIQUE

Simuler l'empreinte environnementale des centres de données

9 AVRIL - 15 JUIN 2018

LABORATOIRE DE L'INFORMATIQUE DU PARALLÉLISME
École Normale Supérieure
46 Allée d'Italie - 69364 Lyon

Maître de stage
Laurent LEFEVRE

Étudiant
Bastien MARSAUD

Responsable pédagogique
Hamamache KHEDDOUCI

Il peut ensuite modifier n'importe quel modèle en cliquant sur les cellules du tableau. Il peut également supprimer un périphérique grâce au bouton sur la droite.

3.1.4 La saisie des autres périphériques

L'utilisateur peut également saisir les périphériques de stockage et les périphériques réseaux dans des écrans similaires à l'écran de saisie des périphériques de calcul. Cependant comme il n'existe pas de base de données pour ces équipements, il n'y a pas d'autocompletion. L'utilisateur devra se référer au manuel constructeur afin de définir la consommation d'énergie de son matériel.

3.1.5 La gestion de la chaleur

A partir des données entrées, le simulateur calcule automatiquement la dissipation de chaleur dans le centre de données. La méthode de calcul est basé sur un livre blanc de APC, une filière de Schneider Electric.
Pour répondre a cette quantité de chaleur, l'utilisateur peut choisir différentes formes de refroidissement dans la liste déroulante et les combiner. Comme certaines sources de refroidissement consomment de l'énergie, on laisse à l'utilisateur la possibilité de l'indiquer.

FIGURE 14 – L'écran permettant de choisir les méthode de refroidissement

3.1.6 La réutilisation de chaleur

Si le centre de données réutilise une partie de la chaleur créée par l'équipement informatique, l'utilisateur peut l'indiquer dans un écran dédié. Il peut également indiquer la quantité d'énergie utilisé pour ce retraitement de la chaleur. Cette information est importante car elle est prise en compte par certains indicateurs.

37

Several subjects specific to data centers seem important to us to treat:

- The aggravation of the urban heat island effect, notably on vulnerable territories (vulnerable, aged populations…);
- Water consumption and pressure on infrastructures;
- Energy consumption and pressure on infrastructures;
- Noise pollution and possible use conflicts with nearby residents and businesses.

Integrating infrastructural mediation into the development policy of third places and the revitalization of town centers

The report delivered in late 2018 to the government, treating third places and titled "Doing together to live better together"[176] stresses the issue of supporting and developing third places in France, spaces for learning, training, living and doing together but also a place for the potential redeployment of public services. This question is moreover related to the national dynamic of reflection on redynamizing medium-size cities and town centers.

We stress here the relevance of including and crossing infrastructural digital mediation questions (learning to create one's own ISP, managing data storage and/or a private cloud for third places…) with those of the ecological transition. The report additionally recommends "making third places the entrance to the digitizing of the territories" but also training places for the digital professions.[177]

[176] http://s3files.fondation-ta.org.s3.amazonaws.com/Rapport%20Mission%20Coworking%20-%20Faire%20ensemble%20pour%20mieux%20vivre%20ensemble.pdf

[177] Notably the creation of sectors of the future with the Competencies Investment Plan: access of young people without a secondary school diploma to developing professions in the digital: equipment maintenance, network administration and IT security, development and coding; but also with "second-chance schools"/ "digital plumbers": a three-month training program for school dropouts between 17 and 24 years old: rollout of optical fiber, racks and cabling, simple network administration.

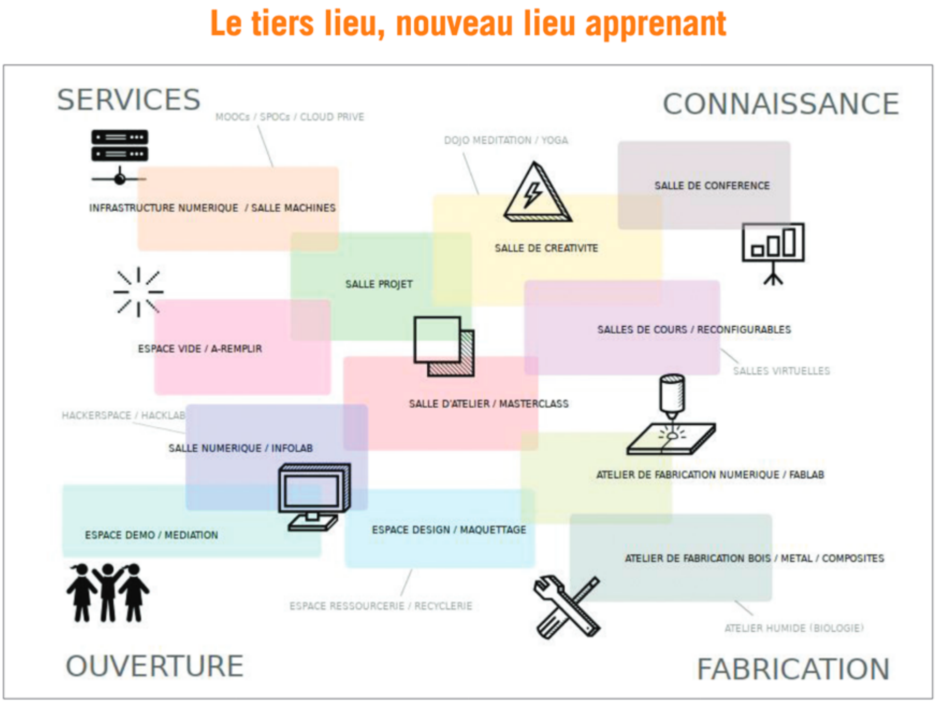


Figure 39. Diagram taken from the report "Doing together to better live together," p. 149

8.3 Energy recommendations

Supporting and evaluating sobriety

The Shift Project report by the Lean ICT working group mentions a certain number of recommendations, some of which have already been put forward, especially by the EcoInfo group:

- To adopt digital sobriety as an action principle
- To speed up the awareness on the environmental impacts of the digital sector
- To integrate environmental impacts as a criterion for decision
- To give organizations tools and references so that they can lead their digital transition in a more environmental-friendly way
- To implement carbon emissions evaluation for digital projects
- To deploy those measures at the European level

To these could be added:

- **Sorting data**: favoring data with a high social and environmental added value.[178] The question of data sorting is raised as for other types of "waste" because data pollute – some are to be eliminated because they have no added value (or even to not be produced), others are more interesting to keep because they are usable or useful. Will the principle of the polluter-payer be applied one day to further encourage sorting them to reduce storage spaces and the energy used?

- **Disseminating sobriety practices in public contracts** related to IT, as for example with the contribution of GDS EcoInfo to the MatInfo4 framework agreement (for the higher education and research market) that affects most of the universities and research institutes in France: https://www.matinfo-esr.fr/ecoinfo

[178] Interview with Valérie Peugeot, prospective specialist at Orange Lab, March 28, 2018.

Reconciling energy planning and urban planning

a) Anticipating the data center program in urban projects and the related network connections, in particular the electricity and optical fiber networks. If the program is not integrated into the project from the beginning, the network costs can become very high, even blocking. The idea of the single-stop service, as was developed in Santa Clara, California (see first part of the report) could consequently be rolled out in certain conurbations or metropolises and improve the integration of data center projects.

b) Better anticipate electricity needs in all the large projects in the Île-de-France.

In this way, a 10-20-year vision would permit Enedis to:

- Better project the needs of clients and deliver the power requested without too long delays;
- Give an opinion on territorial development to say where available power is. This would make it possible to rationalize the occupancy of the territory by minimizing the creation of new infrastructures (and therefore the cost for the local administration).

This has a threefold interest:

- For the local administration that would better control the modalities of its urban development;
- For those who develop infrastructures like Enedis, to be able to intelligently anticipate, without oversizing, and to meet the need as closely as possible;
- For the client, this would not be competition of the first come first served but a fair division of costs, like the share principle in the Regional Schemes of Connection to the Renewable Energies Network (S3REnR).[179] Consequently, very large electricity users pay (pro rata of its power) a share to participate in financing infrastructures of the public network.

c) The end of overbooking that can be blocking for the territories.

The idea here is to limit the gap between the connection power requested and the power finally subscribed, in order to avoid oversizing of infrastructures for calls for power that will never take place. The possibility of a review clause to avoid overbooking seems interesting.

d) Sharing data with public authorities.

For a program like Data Center Parks in Stockholm to be implemented, what is required on one hand is the mobilization of the local administrations, with the right planning scale, and, on the other, legislative adaptation so that the Enedis data on the location of the available and reserved power can be made available to the planning administrations. If these data cannot be shared with a private operator or publicly because of the client's confidentiality concerns, they could be made available to a public entity, in charge of territorial development.

So that the energy planning actors take a stronger hold of the subject

One track would consist in energy producers/operators being able to have their clients make energy saving and develop renewable energies with an incentive policy and rates. There are probably reflections to be carried out to try to better guide, even force the choices of data center operators and their requests for power.

- This is a subject that concerns Enedis, but also RTE for large power (above 40 MW). Historically, the "public service" culture is focused on meeting the client's needs without questioning them, however, at this period of climate and environmental urgency, certain

[179] This is a form of pooling costs applied in the framework of the Regional Schemes of Connection to the Renewable Energies Network (S3REnR), stemming from the Grenelle II law. For the renewable energy installations (individual or grouped) above 100 kVA, a share is invoiced to the producer, in addition to the connection cost. In this way, every renewable energy producer pays (pro rata of its power) a share to participate in the financing of works created on the public networks to receive these renewable energies.

demands could be made by the energy operators that, depending on the projects, could prioritize certain sites.

- The invoicing of electricity connections could be reviewed, notably on backup or in the event of a multiplication of sites. To avoid the scattering of infrastructures, it could be decided that the value incumbent on the data center on a first site requested be that stipulated by the texts, then if there is a second site requested, it doubles; and if there is a third site, it triples.

Favoring and organizing heat recovery

- To integrate the waste heat of large corporate or colocation data centers into the urban heating networks, the idea is to take into consideration very upstream the location, as in Stockholm, and to offer compensations for this (lower rate, energy exchange: heat against cold, for example).

- To accompany the data center operators in the implementation of heat recovery projects, their follow-up and maintenance, the creation of an intermediate actor proposing assistance services to the project management seems interesting with a mandate to develop waste heat recovery with a maximum of actors and not solely the data centers.

- To draw up precise spatial maps that would cross:
    - The available or potentially available electricity capacities of Enedis and RTE;
    - The heating needs, heating networks connected to the new urban projects;
    - The Internet networks, with available bandwidth and quality of connection.

  This would concern guiding to the maximum the installation of data centers in the most favorable zones based on the parameters established.

- To favor the development of medium-size data centers in public-private programs, to encourage pooling between buildings as in the case of the operator Céleste in Noisy-Champs (77) that uses the waste heat of the servers to heat its offices. Heat recovery for offices, housing or logistics spaces in the immediate vicinity is a more common reuse scale.

Developing renewable energies and micro-networks

- To favor renewable energy production onsite when this is possible. To integrate the dormant infrastructures of data centers into the local energy systems (see section below).

- To develop and facilitate collective self-consumption, whose first application stemmed from the law of February 24, 2017 and it application decree of April 28, 2017.[180] The data center operators could make their dormant backup infrastructures available since the law aims at relieving the network by favoring projects in which consumptions and productions are balanced in real time (see the example of Portland General Electric in the first part of the report). Beyond self-consumption, it is the development of micro-networks or private networks for data centers that could be developed. They would necessarily be connected to the network for security reasons in the event of an incident or stabilization problems with the electric wave.

- Concerning the collective self-consumption rates, Enedis would like to obtain a remuneration no longer per kWh transmitted (as is the case today with the transmission rate, see TURPE 5), but the power available. With the bidirectional flows of smart grids, the remuneration per kWh transmitted is for the energy operator contestable because this system could threaten the financial equilibrium that enables it to ensure investment and maintenance costs.[181] With the energy transition and the multiplication of onsite renewable energy productions, the clients will

[180] If the legal framework of collective self-consumption is too restrictive for citizen initiative projects, it is for the moment more intended for professional structures like electrification syndicates, social housing landlords, real estate developers and other developers that can be the legal entity in which the self-consumers are grouped.

[181] For Enedis, the current rate of collective self-consumption is problematic, notably for clients that request very few kWh on the distribution networks (only a few hours a year when their production is insufficient) because they do not contribute to a fair use on the network.. Whether the infrastructures built are used for 8,760 hours or one hour a year, they have the same investment and maintenance cost.

increasingly need electricity security in the event of a problem on their micro-network (with the availability of power during a given time). The advantage of this change would be to limit excessive requests for connection power that habitually come from data center operators. However, this measure remains problematic because it would lead to favoring large clients and penalizing residential customers who would see their connection costs increase (vis-à-vis their subscribed power).[182]

Integrating dormant infrastructures into local energy systems

The emergency generators of data centers can have a new role in smart grids.

- Repairing, mobilizing and pooling emergency generators;
- Transforming emergency generators into active production units (cogeneration or trigeneration);
- Diversifying and decarbonizing primary production resources: gas, biogas, biomass;
- Developing micro/macro-grid complementarity, by systemizing the smart grid principle used in Portland or New York City (the example of the New York Times building) whose backup generators are used by the local electricity company and shift onto the building's nano-grid in the event of a supply problem.

Favoring infrastructural diversity

In a development perspective encouraging the installation of local micro-productions and interconnected micro-networks, what must be carefully measured is that each technical reality implies a relational system (governance), an operational functioning (technical) and a metabolic chain (energy-resource-environment) specific to the territory in which they are installed. The geographic level of pooling and the degree of autonomy of certain service loops (total or partial), just like interconnection, are a strategic conundrum that is not reproducible. Infrastructural heterogeneity and diversity dominate. Micro-networks or technical micro-systems can be connected to each other. This interconnection relationship is envisaged between different entities: the building, the block, the neighborhood, the city, the territory, the whole forming a sort of energy Meccano of territorial solidarity.

In this section, three perspectives some of which were notably identified by the French Energy Regulatory Commission (CRE)[183] could be developed:

- The top-to-bottom hierarchical architecture of the large electricity networks will evolve toward a model connecting clusters of micro-networks (some of which could be those of data centers);
- As a flexibility instrument, battery storage will become an essential component of the electricity system, notably data centers;
- The emergence of new technologies will enable certain industrialists or consumers to take control of their own energy supply and its consumption; and perhaps one day its distribution with the approval of the regulatory authority.

8.4 Research and knowledge recommendations

We have identified the following subjects as strategic to be gone deeper into to ensure a better spatial and energy integration into data centers in the territories:

- Evaluating the specific climate risks for digital infrastructures in France;

[182] This is the calculation that was made on the level of the TURPE 5. It led to a rise in rates to the disadvantage of small clients that do not systematically use this power, whereas it would be very favorable in the case of a data center, whose subscribed power will be almost always constantly used at 80-90%.

[183] http://fichiers.cre.fr/Etude-perspectives-strategiques/1SyntheseGenerale/Perspectives_Strategiques_du_secteur_de_l_energie_Synthese_generale_FR.pdf

- Studying the feasibility of an intermediate operator on waste heat recovery from data centers (legal structure, economic model, governance…);
- Assessing the ecological impact of associative, cooperative, decentralized, distributed and peer-to-peer data processing and storage infrastructures;
- Examining the potentials and modalities of the development of infrastructural mediation in third places in France;
- Conducting a complementary study on the issues of urban, energy and territorial issues of hyperscale data centers and micro-data centers (edge);
- Simulating the impact of “smart” projects on the environment: tools to be developed for ecological reviews of projects.

Conclusion

Between the United States and France (respectively the first and fourth countries in terms of data center installation), cooperation between actors diverges. This cooperation is more developed in the United States than in France with corporate groups between companies that carry out experimentations (Facebook's Open Compute Project, Silicon Valley Council Leadership, BSR™ [Business for Social Responsibility]) and a single-stop service dedicated to local administrations (Santa Clara, Hillsboro, Prineville). The examples of pooling are consequently more numerous. As for energy initiatives for renewable energies, we can see a strong commitment on the part of American operators to exit fossil and nuclear mixes and lay claim to 100% renewable energies. American data center industrialists are clearly a driving force of the energy transition by exerting a form of pressure on the old utilities. It is equally onsite or nearby production with individual and collective self-consumption and the actors' involvement in distribution that differs from France. In a very open market, there is very strong competition between the digital actors and the historic electricity companies, the former sometimes working to make the latter seem obsolete, as shown by this statement by Brian Janous, the energy strategy director at Microsoft: "How do you deliver reliable energy to a more engaged and dynamic customer base when your power supply is increasingly renewable and therefore intermittent, all in a system that has not really changed since the early 1900s?"[184]

This "belatedness" favors an offensive dynamic of GAFAM on the energy market with a mixture of genres that is worrying since these companies are large consumers of electricity: they create the increase in their electricity demand themselves through the increase of the data market and their storage from which they draw immediate benefits. In this supply policy, their potential arrival on the energy market that will increasingly function based on smart grid data management raises questions.

If the energy performance of buildings is globally improved (with the race to a PUE closer to 1), it remains insufficient vis-à-vis the growth of data to be stored. The problems of pooling and the search for a common interest between data center operators and territories clearly shows that the sector and its territorial impact remain guided by economic and financial objectives.

The purpose and ethics of a big data company and the smart city remain inadequately questioned by public policies and the local administrations, trapped by the illusion of growth of the digitizing of the world from which a few effects are expected on their territory. The smart city project initiated by IBM and Cisco is accompanied by its most efficient ambassadors and data extractivists: Google, Amazon, Facebook, Apple and Microsoft. These Big Tech companies have for the last decade taken part in radically transforming not only the economy and social practices, but also digital spaces and infrastructure. Beyond the smartphone and the Internet, software programs and social networks that they helped found and whose major services they represent (search engine, online sales, geolocalized mapping, social networks, hardware and software), they are now storming architecture, cities and territories with the data as currency. Sidewalk Labs, the Alphabet entity (Google) dedicated to the smart city may build a district in Toronto, testing there a closed digital loop on its future inhabitants: collecting data, processing them, adjusting the project and once again collecting, processing, adjusting… to continuously optimize the district's functioning, from A to Z as the name of the group suggests. Apple is developing an Apple Energy subsidiary, authorized by the American government (FERC), to be able to control its energy supply. Facebook and Microsoft are strongly positioned on the development of energy and electricity micro-networks on their own office sites and data centers, but also elsewhere, with the creation of the Microgrid Investment Accelerator that is financing and marketing electricity micro-networks throughout the world. The diversification of GAFAM to urban services is not completely new, but the convergence of their monopoly position on the collection and storage of personal data, on software, commerce and communication, on the media and culture, that is, all the exchanges of goods and information, from contents to dissemination networks and storage spaces, brings with it major democratic risks. Their determination to incarnate, each in its own way, this urban performance ideal through a new neighborhood, a new corporate headquarters, a new city seems however to ratchet up their claim to compete with the local administrations and the federal government.

Another smart city however is possible, one that would be more sober and measured in its tools and practices, closer to the citizens' interest and concerned with social justice. Since the monopolistic power of GAFAM ramped up, and even earlier, movements on the reappropriation of the Internet infrastructure,

[184] https://blogs.microsoft.com/green/2017/05/17/how-microsoft-technology-is-enabling-an-autonomous-grid/

network and storage are being strengthened as we have shown. It is interesting to see that the Internet infrastructure (and not only its uses) has also followed the reappropriation movement that can be observed in the energy sector with the desire of many citizens to choose their energy sources (local and renewable), to pool services or become involved in energy communities. This other smart city, collaborative and peer-to-peer, is being disseminated on the small scale. It is steered by citizen groups that reflect on the control of their data and a more distributed and decentralized energy Internet. An example is the commune of Prats-de-Mollo-la-Preste, South of France, which is currently reaching energy autonomy with the support of the Régie Électrique Municipal (the commune's energy control entity), then of the S.E.M. Prat's Enr (concerned with renewable energy) and that is trying to establish an energy transition system by relying on the model of the blockchain technology to think about transactions and exchanges. Reach-action networks like La Myne and Daisee are reflecting on the use of public blockchains to develop short energy circuits in order to recover not only production but here too management (and the data) linked to self-consumption and therefor the added value for local groups that would ensure it (connected to the large network). The principles of these distributed (and interconnected) micro-networks are very different from the smart grid principle developed by the major operators of the traditional network who think of local micro-productions as an import-export reserve for the benefit of the large network. Beyond an Internet of distributed energy, experimentations still few in number are emerging for data centers of proximity, more low-tech, autonomous and locally managed: this is notably the case of the one at Rutgers University in New Jersey

A part of the world of architecture and urban planning still tends to minimize, today, the immense soft power of the smart city on our way of thinking about the future of cities and territories. The digital is not growing, it is transforming. It is not an urban exoskeleton that can be put on and taken off at one's leisure, but a pervasive system that is gradually modifying urban forms, relying on an infrastructure that is taking an increasing amount of space (energy production units, storage center, ocean cables, land-based networks, but also electronics equipment production factories, digital dumping sites…). If the question of the materiality of the digital technical system and its environmental impact (energy as well as rare ores) is beginning to be brought up more often, the continuous frenzied technological innovation race never stops limiting the urban digital imaginary dimension to a univalent discourse that makes the digital, progress, hyper-sophisticated technology and "green growth" inseparable, whereas many alternatives exist.

The territories' support of access to a free and open Internet is as indispensable as a broader reflection on the data center object and the related digital system; to better measure the environmental impact of the technical choices in light of the expected social added value; and to shift toward more reasoned, sober digital practices that focus on degrowth.

ANNEXES

Annex 1: standards and frameworks

INSEE classification

The NAF code of data centers is "Subclass 63.11Z: Data processing, hosting and related activities."[185]

Regulatory framework

- **ICPE regulation**

Several data center facilities are subject to the ICPE regulation, defined in Book I and Book V of the Code of the Environment. This regulation is above all for large data centers. Although not every data center falls under the same headings of the ICPE nomenclature in their operating authorizations, several headings come up regularly and illustrate the main sensitive poinst of data centers:

- Heading 2910 related to "combustion installations." This heading concerns the generators of data centers. The data center needs an authorization if its generators have a power above 20 MW.
- Heading 4734 related to the storage of "specific oil products and replacement fuels" or heading 1432 related to "storage in manufactured tanks of inflammable liquids." These headings concern fuel tanks. The data center needs an authorization for over 1,000 tons of stored products (heading 4734) or over 100 m^3 (heading 1432).
- Heading 2925 related to the charge of accumulators. For this heading, only a single declaration is necessary.
- Heading 2920 related to the "installation of compression functioning with effective pressures above 10^5 Pa and compressing or using inflammable or toxic fluids." This heading concerns the cooling units of data centers. An authorization is required if the absorbed power is above 10 MW.

The decree of November 14, 2014 completing Article R. 512-8 of the Code of the Environment stipulates that as of January 1, 2015, in the event of renovations or new constructions, the ICPE of a total power above 20 MW must conduct studies to examine the profitability of waste heat recovery via a connection to the heating or cooling network.

- **OIV regulation: Operator of Vital Importance**

Data centers also fall under the regulation related to OIV, defined in the Security Code in Article R 1332-1. The obligations of operators of vital importance are presented in the general interministerial directive no. 6600/SGDSN/PSE/PSN of January 7, 2014. This regulation aims at protecting installations "whose unavailability would risk weighing heavily on the potential for war or economic potential, the security or the capacity of survival of the nation (Article L 1332-1 of the Security Code)

- **European Code of Conduct for data centers**

This code is not a regulation but a text bringing together good practices for data center operators. The idea is to compensate operators that incorporate an improvement and efficiency logic. This code of conduct was launched in 2008 and is reviewed every year. It should in the long run serve as a basis for the writing of standards. GIMELEC participated in the writing of this document for France. This document ranks good practices from 1 to 5: 5 represents what is difficult to attain. These good conducts concern

[185] https://www.insee.fr/fr/metadonnees/nafr2/sousClasse/63.11Z?champRecherche=false This subclass includes the supply of infrastructures intended for hosting services, data processing and other similar activities. It includes specialized hosting activities like hosting services for websites, applications or streaming services and the availability for clients of IT installations with shared time on large computers. The data processing activities include complete processing services and the preparation of specific reports based on data provided by the client, specialized input services and automated data processing, including database management activities.

subjects such as the equipment used (inverter, cooling system, servers), the follow-up of the consumption of devices or the location of the data center (region with a hot or temperate climate).
This code of conduct is also accompanied by work on the sector's standardization. We can cite for example, the technical standardization committee CLC/TC 215 that is working on a series of EN 50 600 standards that set the general framework treating data centers. This standardization work on the European and international scale is the first step toward legislation on these infrastructures: a decree cannot be brought forward without preliminarily defining data centers.

- **ASHRAE 90.4**

The American Society of Heating, Refrigerating and Air-Conditioning Engineers, an international technical organization founded in 1894, publishes worldwide standards on heating, refrigerating and air-conditioning engineering. It has published a specific standard for data centers: the 90.4 standard

- **Regulations and planning**

There are no regulations specific to data centers either in local urbanism plans (PLU) or in the SCOT. In the Île-de-France, these digital infrastructures are never taken into account as such in territorial planning (PLU and SCOT) apart from a few words in the PADD, but without any regulatory variations. If is SCOT is a territorial variation of the SDTAN (territorial guidelines for digital development), it brings up above all questions of digital coverage.
The SCORAN (regional coherence strategies for digital development) establish the major orientations desired by the regional actors, in order to guarantee that each territory is covered by an SDTAN.
The SDAN (digital development guidelines)[186] focus on access to high-speed broadband and the rollout of optical fiber in the territories. They can mention data centers but more as fiber customers, in the same way as other companies, than as being part of strategic infrastructures of the digital, and without bringing up the spatial and environmental aspects.
The SDUS (guidelines for digital uses and services) accompany the development of new services: e-health, e-administration or e-education, related to the needs of the citizens.

[186] Article 23 of law no. 2009-1572 of December 17, 2009 related to the fight against the digital divide introduced in the CGCT (General Code for Territorial Administrations) the Article L 1425-2 that stipulates the establishment, on the initiative of the regional administrations, of an SDAN on the level of one or more administrative departments or regions.

Annex 2: research projects underway on the energy efficiency of data centers

- **ANR (National Research Agency)**

L'ANR has financed certain projects on the energy efficiency of data centers. The **DATAZERO** project is currently analyzing the concept of robust data centers that use renewable energy.
http://www.agence-nationale-recherche.fr/projet-anr/?tx_lwmsuivibilan_pi2%5BCODE%5D=ANR-15-CE25-0012

CTRL Green: Autonomous Administration of Green Data Centers
http://www.agence-nationale-recherche.fr/Projet-ANR-11-INFR-0012

- **European Union**

DOLFIN (Smart Grid and Demand Response)
"DOLFIN foresees a group of energy-aware data centers, operating in geographically dispersed locations, in a collaborative manner. Over this group, DOLFIN will design, implement and deploy a solution that will allow the dynamic reallocation of the workload and virtual machines to data centers, where ICT resources and/or cooling facilities are more energy/cost effective.
"DOLFIN data centers will be interconnected with the smart grid network, providing responses on the changing demands for energy. In this respect, DOLFIN will contribute in energy stabilization of the power distribution system."

GEYSER
"The GEYSER Vision is based on the premise that data centers will act as accomplished energy prosumers within tomorrow's smart cities. They will be adept at using [a mix of] of available energy sources as well as catering for flexible management of the ICT workload. This will enable the data center to optimize its energy demand by continuously selecting the most attractive energy profile available."
http://www.geyser-project.eu/project

GreenDataNet
"GreenDataNet intends to design, validate and demonstrate a system-level optimization solution allowing a network of urban data centers to collectively improve their energy and environmental performance, and act as a resource for smart grids."
This project concerns the integration and management of renewable energies in data centers.
http://www.greendatanet-project.eu/media.html

RENEWIT
"The main objective of the RenewIT project is to develop a simulation tool to evaluate the energy performance of different technical solution integrating RES [renewable energy systems] in several European climate regions."
http://www.renewit-project.eu/the-project-data-centres-renewable-energy-tool/

NESUS: Networking projects like the Nesus project address the issue of hyperscale systems with a sustainable development. www.nesus.eu

Annex 3: details of the area and power calculations for the data centers of Plaine Commune et Saclay

The figures given for the available electrical power come, in order, from:

1. The communication of the operator of the data center studied (sometimes it is the available power onsite that is provided, sometimes the power of the servers from which the total available power can be extrapolated).

2. The power of the generators present on the site. For the largest sites, these figures can be found in the authorization orders to operate from the ICPE (thermal power and electrical power not to be confused – see below).

3. From an extrapolation made using the average electricity concentration of server rooms: The average electricity concentration of server rooms in data centers is about 1,700 W/m². The energy density varies a great deal between the different sites and the data center generations. The average used here was calculated on the basis of the Île-de-France real estate of Interxion, including data centers of different periods. In 2014, this operator communicated on the electricity concentration of its rooms that varied from 900 to 2,500 W/m² with an average value of 1,700 W/m².

The figures given for the areas come from:
1. For the areas of the plots: the areas come from the land registry, or if necessary were measured based on Géoportail.
2. For the floor areas: the areas come from the building permits that we were able to consult.
3. For the IT areas: The areas can come from the authorization to operate decree reports of the ICPE, building permits or the communication from the data center operator. As a last resort, we had recourse to an extrapolation, which is possible if one has the IT power of the site.

The elements used for the extrapolations are the following:
1. The distinction must be made between the power of the servers and the power available for the site. It is difficult to be perfectly exact on these values but the following tendency can be used: $P_{available} = 3 * P_{IT}$
    - This approximation is explained by the presence of air-conditioning that can represent up to 50% of a site's electricity consumption, and on the need for electricity redundancy of the site. This hypothesis is supported by well-documented cases of data centers and our meeting with Mr. Khun, the architect who handled many projects for Interxion.
2. A purely theoretical hypothesis is used as a last resort. In examining the sites whose IT area is already known, it can be seen that the following comes out on average to: $\frac{IT\ area}{Footprint} = 0.73$

    Average for nine values with a typical spread of 0.13 (or 18%).
    - This hypothesis is only valid for data centers located in a dedicated building.
    - This hypothesis is solely used to have an order of magnitude for the data centers whose location is the only element we know. The footprint is measured on Géoportail.

3. It is also possible to determine the available power of the site through information available on the generators. An example with the DATA4 generators on the Marcoussis using documents included in the building permit:

The DC3 data center is equipped with three generators of 2,500 kVA each, including one for redundancy. In the building permit, we find that the installed thermal power of is 44,794 kW for each generator, or 14,382 MW of installed thermal power for the building.
This value is calculated using:
- CV (caloric value of fuel oil): = 42,720 J/kg
- SC (specific consumption of the motor): = 0.202 kg/kWh
- Rp (rated power of the motor): = 2,000 kW

Calculation of the thermal power: $P_{th} = CV * SC * R_p$ (attention to time units)

These generators therefore have an efficiency of $\frac{P_{elec}}{P_{th}} = \frac{2{,}000}{4{,}797} = 0.42$

4,797 kW of thermal power must therefore be supplied to obtain an electrical power of 2,000 kW. The generator consequently has an efficiency of 42%.

In the ICPE files, the announced power is that of the maximum thermal power. For an approximation of the electricity consumption of the site, this efficiency of 42% must therefore be taken into account.

Annex 4: interviews conducted by Cécile Diguet and Fanny Lopez.

Mark Alatorre, engineer, California Energy Commission, Sacramento, California.

Guy Allee, engineer, Intel, Portland, Oregon.

David Ashuckian, deputy director of the Efficiency Division, California Energy Commission, Sacramento, California.

Wazim Aziz, regional director of Zayo, New York City, New York.

Roger Baig Viñas, founder of Guifi.net, Barcelona.

Crystall Ball, public relations supervisor of the Bonneville Power Administration (BPA), Portland, Oregon.

Daniel Balouek, researcher at the RDI2 laboratory, Distributed Systems and Resource Management, Cloud/Edge Computing and IoT, Rutgers University, New Jersey.

Benjamin Bayard, cofounder of the Quadrature du Net, co-president of the Fournisseur d'Accès à Internet associatifs federation (FFDN), Paris.

Gustav Bergquist, vice president and head of operations at Multigrid Data Centers, Stockholm.

Eric Bothorel, LREM deputy, in charge of the digital, Paris.

Thomas Bourgeois, CHP specialist, Pace Energy and Climate Center, New York City, New York.

Edward Ted Borer, energy plant manager at Princeton University, New Jersey.

Don Bray, director of account services, Silicon Valley Clean Energy, Sunnyvale, California.

Anders Broberg, Stokab, head of communications, Stockholm.

Eric Carter, senior transmission and customer account executive, Bonneville Power Administration, Portland, Oregon.

Axelle Champagne, executive vice president, EPCI Paris Saclay.

Matthew J. Chancellor, regional business manager, PacifiCorp, Bend, Oregon.

Mathieu Chazelle, engineer, architect and founder of Enia architectes, Paris.

Yen Han Chen, project planner, city of Santa Clara, California.

Richard Clark, manager of the data center campus of Vantage, Santa Clara, California.

Mark Clemons, economic development department director, Hillsboro, Oregon.

Frédérick Coeuille, director of the Zayo data center, Paris.

Gary Cook, head of the IT department at Greenpeace, editor in chief of reports on the energy impact of digital technologies, San Francisco, California.

Colin Cooper, urban development director, city of Hillsboro, Oregon.

Fabrice Coquio, CEO of Interxion France group, Paris.

Colin Corby, project supervisor, California Energy Commission, Sacramento, California.

Clara Cuso, coordinator in the Guifi.net telecommunications network, Barcelona.

Romaric David, IT department of the University of Strasbourg, Strasbourg.

Kris De Decker, founder of the *Low-tech Magazine* website, Barcelona.

Pierre-Jean Delhoume, energy manager, Uniper, Paris.

Michael Downey, infrastructure and data center project manager, Gensler architects, San Francisco, California.

Fabienne Dupuy, deputy to the territorial director of Enedis in Seine-Saint-Denis.

Antoine Dussouich, deputy director of the Stratégie, à la Performance et aux Nouveaux Services de l'Établissement public d'aménagement (EPA) Paris-Saclay (ex-EPPS).

Scott Edelman, planning director, Prineville, Oregon.

Jason Eisdorfer, utility program director, Oregon Public Utility Commission, Portland, Oregon.

Mickael Evrard, general delegate of the Agence locale de l'énergie et du climat (ALEC) of Plaine Commune, Saint-Denis.

Ben Falber, senior program manager, New York State Energy Research and Development Authority (NYSERDA), New York City, New York.

Erik Ferrand, founder and president of Qarnot Computing, Paris.

Steve Forrester, city manager, Prineville, Oregon.

Efraín Foglia, founder of Guifi.net, Barcelona.

Anish Gautam, engineer, California Energy Commission, Sacramento, California.

Damien Giroud, France Solutions Datacenter director, Schneider Electrics, Paris.

Jim Gallagher, executive director of the Microgrid Initiatives Program for the Department of Energy, New York City, New York.

Wendy Gerlitz, policy director, NW Energy Coalition, Portland, Oregon.

John Gilbert, executive vice president of Rudin Management, real-estate developer (owner of the building 32 Avenue of the Americas), New York City, New York.

Jim Grady, senior director of business development, 365 datacenters, edge data centers, New York City, New York.

Joel Guignard, head of the Agence Marché d'Affaires Île-de-France at GRDF, Paris.

Barry Hooper, vice president of real-estate development at the Department of the Environment of the city of San Francisco, California.

Lisa Hunrichs, urban planner, Portland Metro, Portland, Oregon.

Caroline Humbey, supervisor of the urban planning project on La Courneuve, Plaine Commune, Saint-Denis.

Fred Jalali, data center manager at Zayo in Santa Clara, California.

David Kinney, director, facility engineering and planning, Telehouse Data Centers, New York City, New York.

Eric Klann, city engineer, Prineville, Oregon.

Simon-Pierre Kuzar, EPAPS OIN Paris Saclay, Paris.

Christina Lee, transmission planning engineer, Bonneville Power Administration, Portland, Oregon.

Claire Le Strat, energy transition manager, Communauté d'agglomération Paris-Saclay EPCI, Saclay.

Virginia Lew, energy efficiency research manager**,** California Energy Commission, Sacramento, California.

Stefan Lindbom, Ellevio, Stockholm.

Brigitte Loubet, head of energy clusters, special heating advisor at the Direction régionale et interdépartementale de l'Environnement et de l'Énergie (DRIEE), Paris.

Michael Lozano, engineer, California Energy Commission, Sacramento, California.

Ted Mahl, architect and director of the CAC Architects office, San Francisco, California.

Hervé Mallet, energy director of the Technical and Information Systems èepartment of Orange France, Paris.

Vincent Margout, quality and sustainable development delegate, Grand Paris Aménagement, Paris.

Daniel Meltzer, vice president leasing, Sabey, New York City, New York.

Chris Meyer, manager, Building Standards Office, California Energy Commission, Sacramento, California.

Kevin Mori, engineer, Efficiency Division, Codes and Standards group, California Energy Commission, Sacramento, California.

Anu Natarajan, sustainable development advisor, cabinet of the mayor of Santa Clara, California.

Skip Newberry, president and CEO, Technology Association of Oregon, Portland, Oregon.

Riki Nishimura, director of urban strategies, Gensler architects, San Francisco California.

Mark T. Osborn, engineer, founder and partner of Cadmus Energy Services, Portland, Oregon.

Manish Parashar, professor and researcher at the Department of Electrical and Computer Engineering, Laboratoire RDI2, Rutgers University, New Jersey.

Julie Peacock, director of policy, Oregon Public Utility Commission, Portland, Oregon.

François Pellegrini, professor at the Université de Bordeaux, member of the Commission nationale de l'informatique et des libertés (CNIL), Paris.

Christophe Perron, founder and president of Stimergy, Paris.

Jacques Perrochat, director, France Solutions Datacenter, Schneider Electrics, Paris.

Valérie Peugeot, prospective specialist, Orange Labs, member of the CNIL and the VECAM – former vice president of the Conseil National du Numérique, Paris.

Gaelle Pinson, digital project manager: data centers and the smart city, Société du Grand Paris, Paris.

Guillaume Planchot, heating and cooling network development director at IDEX, Paris.

Michael Poleshuk, vice president, Equinix, IBX Operations northern region, New York City, New York.

Jeff Raker, economic development planner, Portland Metro, Portland, Oregon.

Ted Reid, principal regional planner, Portland Metro, Portland, Oregon.

David Rinard, sustainable development director, Equinix (corporate headquarter), San Jose, California.

Ivan Rodero, professor and researcher at the RDI2 laboratory, Department of Electrical and Computer Engineering, Rutgers University, New Jersey.

Michael Rohwer, ICT director, Future of Internet Power, Business for Social Responsibility (BSR), San Francisco, California.

Betty Roppe, mayor of Prineville, Oregon.

André Rouyer, infrastructure and digital committee director at GIMELEC, Paris.

Erik Rylander, manager of the Data Center Cooling and Heat Recovery, Stockholm Exergi, Stockholm.

David Schirmacher, president of 7x24 Exchange International, president of Reset Advisors, former vice president of operations for Digital Realty, New York City, New York.

Arman Shehabi, researcher at the Berkeley Lab, Energy Analysis and Environmental Impacts Division of Energy Technologies, Berkeley, California.

Phil Stenbeck, planning director, city of Prineville, Oregon.

Eric Sieberath, deputy director of the cabinet at the Communauté Paris-Saclay (EPCI), Saclay.

Thibaut Siméon, cofounder of Critical Building, Fontenay-aux-Roses.

Doug Staker, vice president of business development at Demand Energy, Enel X, New York City, New York.

Wendy Stone, senior key customer representative, Silicon Valley Power, Santa Clara, California.

Bill Strong, regional vice president of operations at Equinix, San Jose, California.

Elizabeth C. Taveras, engineer, project manager, New York State Smart Grid Consortium, New York City, New York.

Letha Tawney, director of utility innovation and chair for renewable energy, World Resources Institute, Portland, Oregon.

Laurent Trescartes, cofounder and director of Critical Building, Fontenay-aux-Roses.

Paul Vaccaro, senior vice president for operations and engineering, Infomart Data Center, Hillsboro, Oregon, Oregon.

Patrick Vassallo, community advisor for local development of Plaine Commune and deputy mayor for the social economy and solidarity, Saint-Denis.

Stanley Voronov, senior manager, IBX Operations, north region, New York City, New York.

Alain Vaucelle, ICT research supervisor for Plaine Commune, Saint-Denis.

Kevin Whitener, Dispatchable Standby Generation smart grid manager at Portland General Electric, Portland, Oregon.

Bibliographic references

Mills Mark P. / National Mining Association American Coalition for Clean Coal Electricity, 2013, *The Cloud begins with coal: big data, big networks, big infrastructure, and big power, an overview of the electricity used by the global digital ecosystem*.
https://www.tech-pundit.com/wp-content/uploads/2013/07/Cloud_Begins_With_Coal.pdf

Cisco, 2018, *Global Cloud Index: Forecast and Methodology*, *2016-2021*. https://www.cisco.com/c/en/us/solutions/collateral/service- provider/global-cloud-index-gci/white-paper-c11-738085.html

Whitney Josh / Anthesis et Delforge Pierre /NRDC, 2018, *Data Center Efficiency Assessment*. https://www.nrdc.org/sites/default/files/data- center-efficiency-assessment-IP.pdf

Shehabi Arman, Josephine Sarah, Sartor Dale A, Brown Richard E, Herrlin Magnus, G Koomey Jonathan, Masanet Eric R, Nathaniel Horner, Inês Lima Azevedo, William Lintner, 2016, *United States Data Center Energy Usage Report*, Lawrence Berkeley National Laboratory, LBNL-1005775.

Guillaume Pitron, 2018, *La guerre des métaux rares, la face cachée de la transition énergétique et numérique,* Éditions : Les liens qui libèrent.

Luiz André Barroso and Urs Hölzle, 2007, “The Case for Energy-Proportional Computing,” IEEE Computer, vol. 40, issue 12, December.

Orgerie Anne-Cécile, Dias de Assunção Marcos and Lefèvre Laurent, 2014, "A Survey on Techniques for Improving the Energy Efficiency of Large Scale Distributed Systems," *ACM Computing Surveys*, vol. 46, no. 4.

Tinetti Benoit, Duvernois Pierre-Alexis, Le Guern Yannick., Berthoud Francoise, Charbuillet Carole, Gossart Cédric, Orgerie Anne-Cécile, Lefèvre Laurent, de Jouvenel François, Desaunay Cécile, Hébel Pascale, 2016, *Potentiel de contribution du numérique à la réduction des impacts environnementaux : Etat des lieux et enjeux pour la prospective*, ADEME final report, 145 pages.

Groupe EcoInfo, 2012, *Impacts écologiques des Technologies de l'Information et de la Communication - Les faces cachées de l'immatérialité*, Éditions EDP Sciences.

Berthoud Francoise, Lefevre Laurent, Gossart Cédric, 2015, “ICT is part of climate change! Can we reduce its impact and apply good practices and tools to other society domains?,” “Our Common Future Under Climate Change,” international Ccnference, Paris.

IDDRI, FING, WWF France, GreenIT.fr, 2018, *Livre blanc Numérique et Environnement.*
http://fing.org/IMG/pdf/Livre_blanc_numerique_environnement_livreblancecolonum.pdf, 2018

Association Négawatt, 2017, *Scénario NégaWatt 2017 – 2050*.
https://www.negawatt.org/IMG/pdf/synthese_scenario-negawatt_2017-2050.pdf, p.8.

Flipo Fabrice, Dobré Michelle, Michot Marion, 2013, *La face cachée du numérique L'impact environnemental des nouvelles technologies,* L'échappée.

Région Île-de-France, 2012, *Schéma Régional du Climat, de l'Air et de l'Energie de l'Île-de-France,*
http://www.srcae-idf.fr/IMG/pdf/SRCAE_-_Ile-de-France_version_decembre_2012_vdefinitive_avec_couverture_-_v20-12-2012_cle0b1cdf.pdf

ALEC, 2013, *Les data centers sur Plaine Commune.* http://www.alec-plaineco.org/les-data-centers/

European Commission, 2008, *Code of Conduct on Data Centers Energy Efficiency*.

Institut de Veille Sanitaire, 2003, *Impact sanitaire de la vague de chaleur d'août 2003 en France. Bilan et perspectives,* October 2003.

DGE-CDC-CGET, 2015 *Guide sur le Cloud computing et les data centers à l'attention des collectivités locales*. https://www.entreprises.gouv.fr/files/files/directions_services/secteurs-professionnels/numerique/guide-cloud-computing-et-datacenters-2015.pdf

Andrae Anders S. G. and Edler Tomas, 2015, "On Global Electricity Usage of Communication Technology: Trends to 2030," *Challenges* 6, 2015, pp. 117-157.

MacGillivray Carrie and Turner Vernon, 2017, "IDC FutureScape: Worldwide Internet of Things 2018 Predictions," web conference: Tech Buyer. https://www.idc.com/getdoc.jsp?containerId=AP43372517

Moriset Bruno, 2007, "Les forteresses de l'économie numérique. Des immeubles intelligents aux hôtels de télécommunications," *Géocarrefour*, vol. 78/4 | 2003, put on line on August 21, 2007.

Lasalle Jones Lang, 2016, *Data Center Outlook. Strong Demand, Smart Growth*, JLL Americas Research report.

ENR'CERT, 2016, *L'efficacité énergétique dans les data centers. Etude gisement du parc français*, ENR'CERT study conducted with the ATEE, the ADEME, the CRIP, the AGIT, the GIMELEC and the CESIT (today France Data Centers). http://www.orace.fr/lefficacite-energetique-data-centers-etude-de-gisement-parc-francais/

Ganeshalingam Mohan, Shehabi Arman, Desroches Louis-Benoit, 2017, *Shining a Light on Small Data Centers in the U.S.,* Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Laboratory.

Bertho Catherine, 1984, "Les réseaux téléphoniques de Paris – 1879-1927," in *Réseaux*, vol. 2, no. 4 1984, pp 25-53.

Agence Anyoji and Beltrando, *Cahier de prescriptions urbaines, paysagères et architecturales, étude de programmation urbaine et économique*, December 2012. Archive du service de la ville.

Veltz Pierre, 2015, *Petite ensaclaypédie*, Éditions La Découverte, Paris.

Feltin Gabrielle, Boutherin Bernard, Canehan Xavier, 2017, "Indicateurs pour un data center efficient ? Mesurer pour améliorer !," JRES.

Navigant, 2015, *Community Microgrid Case Study and Analysis Report,* report prepared for the New York State Smart Grid Consortium. http://nyssmartgrid.com/wp-content/uploads/CommunityMicrogridCaseStudyandAnalysisReport_2015-08-133.pdf

9. Table of figures

THE ADEME IN BRIEF

The Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME) participates in the implementation of public policies on the environment, energy and sustainable development. It makes its expertise and consulting capacities available to companies, local administrations, the public authorities and the general public so that they can progress in their environmental approach. The agency furthermore helps finance projects and research to be carried out in the following areas: waste management, soil preservation, energy efficiency and renewable energies, economies in raw materials, air quality, the fight against noise, the transition to the circular economy and the fight against food waste.

The ADEME is a public organization under the joint supervision of the Ministry of the Ecological Transition and Solidarity and the Ministry of Higher Education, Research and Innovation.

LES COLLECTIONS
DE L'ADEME

ILS L'ONT FAIT
L'ADEME catalyseur : Les acteurs témoignent de leurs expériences et partagent leur savoir-faire.

EXPERTISES
L'ADEME expert : Elle rend compte des résultats de recherches, études et réalisations collectives menées sous son regard.

FAITS ET CHIFFRES
L'ADEME référent : Elle fournit des analyses objectives à partir d'indicateurs chiffrés régulièrement mis à jour.

CLÉS POUR AGIR
L'ADEME facilitateur : Elle élabore des guides pratiques pour aider les acteurs à mettre en œuvre leurs projets de façon méthodique et/ou en conformité avec la réglementation.

HORIZONS
L'ADEME tournée vers l'avenir : Elle propose une vision prospective et réaliste des enjeux de la transition énergétique et écologique, pour un futur désirable à construire ensemble.

EXPERTISES

THE SPATIAL AND ENERGY IMPACT OF DATA CENTERS ON THE TERRITORIES

Summary

Faced with the massive growth of data exchanges and storage needs, the spatial and energy impact of data centers will be increasingly structuring for the territories. Their diversity of uses, actors, size and locations make the reading of their dynamics and spatial effects complex today.

This report therefore aims at providing an image of the data center landscape in France and in three territories in the United States, each representing different spatial and energy situations (dense city, peripheral space, rural).

A potential factor in the imbalance of local energy systems, objects whose urban accumulation and rural dispersion raise questions, data centers are the object here of an in-depth analysis to better understand the new digital territories under construction, the energy solidarities to be built and the alliance of actors to create.

Authors of the study:
Cécile Diguet IAU ÎDF and Fanny Lopez Eavt

English translation:
Eileen Powis

ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie

www.ademe.fr