Environmental impacts of digital technology: 5-year trends and 5G governance

Updated prospective scenarios for the environmental impacts of global digital technology, and proposals for a rational 5G deployment.

ANALYSIS NOTE – March 2021

THE SHIFT PROJECT

Editorial board

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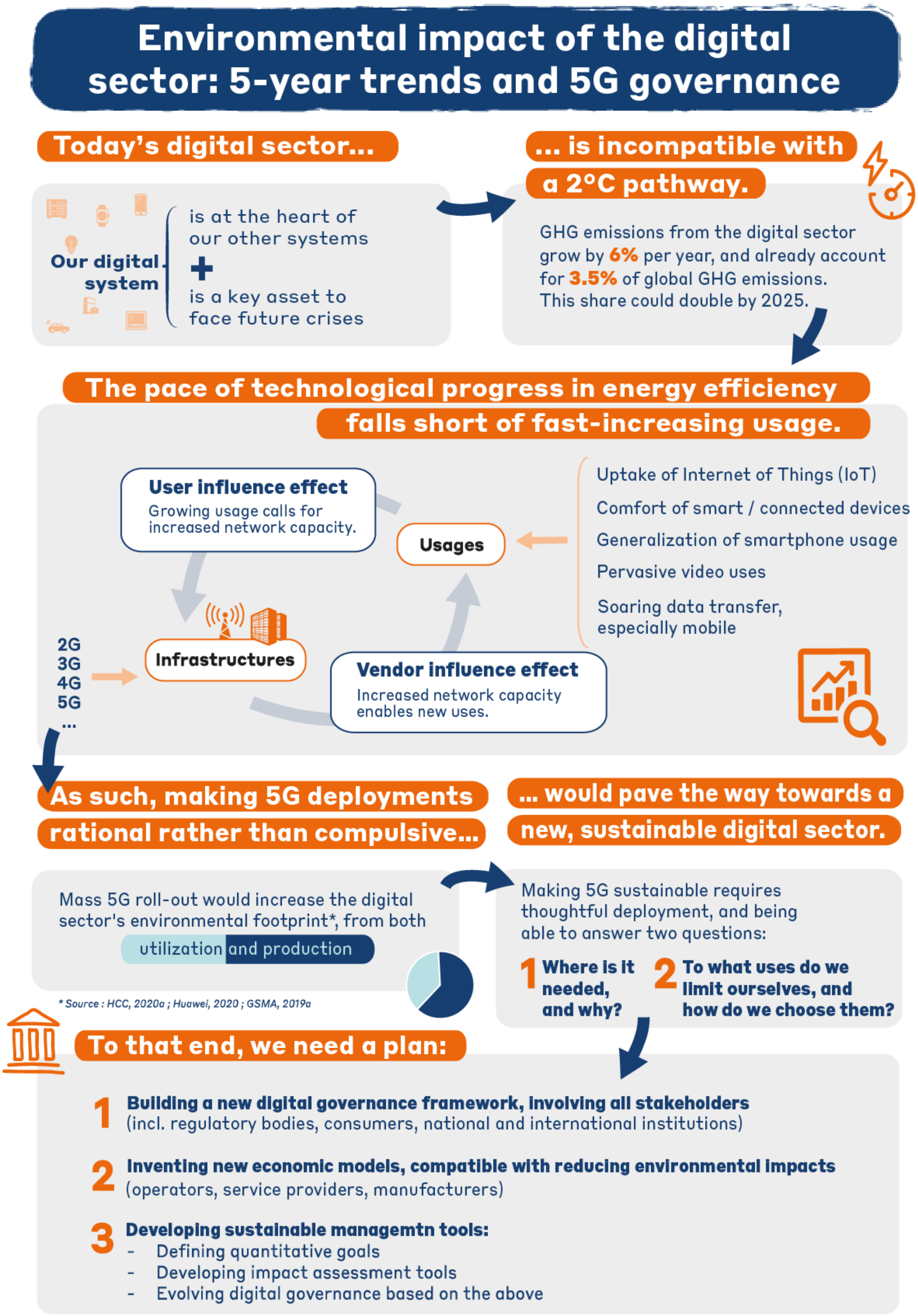
Environmental impact of the digital sector: 5-year trends and 5G governance
Today's digital sector...
Our digital system
is at the heart of our other systems
+
is a key asset to face future crises
... is incompatible with a 2°C pathway.
GHG emissions from the digital sector grow by 6% per year, and already account for 3.5% of global GHG emissions. This share could double by 2025.
The pace of technological progress in energy efficiency falls short of fast-increasing usage.
User influence effect
Growing usage calls for increased network capacity.
Usages
Uptake of Internet of Things (IoT)
Comfort of smart / connected devices
Generalization of smartphone usage
Pervasive video uses
Soaring data transfer, especially mobile
2G
3G
4G
5G
...
Infrastructures
Vendor influence effect
Increased network capacity enables new uses.
As such, making 5G deployments rational rather than compulsive...
... would pave the way towards a new, sustainable digital sector.
Mass 5G roll-out would increase the digital sector's environmental footprint*, from both
utilization and production
* Source : HCC, 2020a ; Huawei, 2020 ; GSMA, 2019a
Making 5G sustainable requires thoughtful deployment, and being able to answer two questions:
1 Where is it needed, and why?
2 To what uses do we limit ourselves, and how do we choose them?
To that end, we need a plan:
1 Building a new digital governance framework, involving all stakeholders
(incl. regulatory bodies, consumers, national and international institutions)
2 Inventing new economic models, compatible with reducing environmental impacts
(operators, service providers, manufacturers)
3 Developing sustainable managemtn tools:
- Defining quantitative goals
- Developing impact assessment tools
- Evolving digital governance based on the above

01

THE ENVIRONMENTAL IMPACT OF DIGITAL TECHNOLOGY: FROM OBSERVATION TO ACTION

Digital technology is fundamental to the stability of our other societal as well as physical systems and one of our key tools to help overcome the potential crises of the next decades, something that has been compellingly demonstrated by the COVID-19 health crisis. Choosing a resilient operating model and giving it a trajectory compatible with constraints on carbon emissions, energy and raw materials is a sine qua non of ensuring that it serves as a reliable asset for our economy and society in the medium and long term.

The central role of digital technology and the need to steer its evolution have fuelled, in recent years, a new broad politicization of technological choices. If environmental impact has become one of the focus points of these collective discussions, it is because digital technology is a physical system like any other (it is based on physical infrastructures, supply-chain realities and availability of significant energy and materials resource). Ensuring the sustainability of the digital system, therefore, first and foremost involves reducing its physical and environmental impacts. This is the aim of digital sufficiency.

In 2018, we produced quantitative indicators on the environmental impact of global digital technology. Without these it would be impossible to objectively assess the place of digital technology in the energy and carbon transition on a large scale (The Shift Project, 2018).

In 2019, we constructed a framework to reflect on digital uses, which connects sociological and behavioural considerations to the physical aspects of our equipment, networks and online services (The Shift Project, 2019).

In 2020, our "Deploy Digital Sobriety" report went beyond these findings to address the specific questions of sobriety by offering operational tools enabling players in the sector to get started on their transition journey (The Shift Project, 2020).

This analysis follows up these reports and fulfils two objectives:

- **Consolidating the quantification** of digital technology's global environmental impact, which provides the context for the ideas expressed above, via an update of our 2018 scenarios;

- **Using 5G deployment as a real-life use case, illustrating** what the application of digital sobriety would bring to the elaboration and management of our technology choices.

The debate on our technological choices is not about technology's intrinsic value. Fruitful debates must question the motivations that guide the way we develop the interconnected systems on which we rely to ensure that their implementation has a justifiable impact on society. Reconsidering the debate over 5G implementation will demonstrate the need for a broader collective discussion on how we effectively govern technology choices to achieve given objectives.

02

THE GLOBAL IMPACTS OF DIGITAL TECHNOLOGY : UPDATED PROSPECTIVE SCENARIOS

I. Model consolidation confirms unsustainable trends in the digital sector

The model presented here [The Shift Project - Forecast Model 2021] is available in full at:

https://theshiftproject.org/wp-content/uploads/2021/03/Pdf-Modele.pdf .

A. Scope of the modelling

1. Technological scope

Given the speed of technological evolutions, the frontiers of digital technology are shifting. For our model, we have adopted a definition consistent with the one currently used by leading players in the digital sector in their forward-looking approaches (Cisco, Gartner, etc.).

The scope of the equipment (and associated uses) chosen for the energy and environmental footprint calculations is therefore as follows:

- **Telecommunication networks** (access and transport, fixed, WiFi and mobile devices),
- **Data centers** (knowing that this label covers very diverse operational environments),
- **Terminals and peripherals**: personal computers (desktops and laptops), tablets, smartphones, regular cell phones, set-top and internet boxes, connected audiovisual equipment (including connected televisions, game consoles, virtual reality headsets), printers, connected speakers, surveillance cameras, screens,
- **IoT connection modules** (Internet of Things)[2].

[2] The Internet of Things (or IoT) is the global infrastructure for the information society, enabling advanced services by interconnecting things (physical or virtual) based on existing and evolving interoperable information and communication technologies (International Telecommunication Union, 2012). Connection modules are integrated into the object (e.g. a light bulb or frying pan) or equipment (e.g. refrigerator or oven). These modules include several integrated circuits allowing them to interact with objects or equipment, processing data and to communicate via a wired or radio interface with a gateway or central management unit, itself generally connected to the Internet.

This scope excludes non-communicating automotive digital equipment as well as digital components of industrial production lines, equipment used for audiovisual production, and telecommunications satellites[3]. It is very similar to the scope used in our October 2018 report, even if some categories are slightly more detailed here.

2. Considered life cycle phases

For all the types of equipment defined, **we take into account the production phase** and the **use phase**.

We have not quantified the impacts related to the end-of-life phase, due to the lack of reliable data and, in particular, because of the low proportion of equipment covered by recycling channels (15% worldwide, Baldé et al., 2015). This situation is worrying since it results, not only in a loss of materials, but also in an increasing and largely ignored soil pollution, coming from unsuitable waste treatment sites, or illegal dumping.

3. Geographical scope

The scope of our analysis is mainly global, but we provide additional details on a European and/or French level when the granularity of the primary sources of information allows it.

B. Model description

1. General architecture: a macroscopic approach

In 2018, we reported that there were no global figures based on measurements (even at a country level) of the energy consumption driven by digital usage. **There are still none**. The available estimates are therefore always obtained either by extrapolating measurements made on samples (e.g. a set of operators[4]), or by using more or less sophisticated models. These can be divided in two categories:

- "**Bottom-up**" models based on the inventory of all hardware present in various sub-perimeters and an estimate of the environmental footprint of each unit,

[3] These last two sectors should be integrated given their strong interactions with digital uses and infrastructures respectively but we did not have sufficiently reliable data to do so.
[4] This is for example the approach adopted by Malmodin and Lunden in their 2018 study (Malmodin, J. and Lundén, D., 2018)

- "**Top-down**" models, which select, for data centers and networks, a central variable characteristic of activity (traffic, number of instructions executed, volume of data stored, etc.) and an indicator of environmental intensity (usually energy).

"Bottom-up" models provide even more relevant results when the scope of the study is delimited and all hardware configuration and usage parameters are precisely documented. The scope of our analysis being largely global, **we favour a "top-down" approach, which enables us to absorb disparities** resulting from the enormous diversity of devices and uses, **and to develop socio-economic narratives in the form of scenarios.**

2. Updates to the 2018 model

We have updated the structure of our 2018 model[5] to consolidate it:

- By distinguishing a sub-category within data centres, those of the "**hyperscale**" type[6],
- By taking into account **a greater range of terminals and devices**,
- **By diversifying the sources,** enabling the calculation of reference values for a large number of parameters (embedded carbon footprints for equipment, energy efficiency ratios for networks and data centres, etc.) and their historical evolution rates.

We updated the benchmark in 2019 based on recent data and studies related to the following dimensions:

- **Traffic and installed fleets**

The traffic and installed base data were updated from reports published annually by Cisco:

- Cisco Global Cloud Index, Forecast and Methodology, Whitepaper (Cisco, 2015, 2016, 2017, 2018) describing the qualitative and quantitative characteristics of the data flows processed in data centres during the year preceding the report over a 5-year horizon;

[5] The structure of the 2018 model is based on the model developed by Andrae and Edler in 2015 (Andrae & Edler, 2015), which developed scenarios for the evolution of digital energy consumption from 2010 to 2030. The assumptions of these scenarios are available in the appendix.
[6] These are very large data centres designed to achieve economies of scale and managed by public cloud operators.

- Cisco Visual Networking Index, Forecasts and Trends (Cisco, 2015, 2016, 2017, 2018, 2019) and then the Cisco Annual Internet Report (Cisco, 2020) describing the qualitative and quantitative characteristics of data flows through telecommunication networks and connected terminal fleets, from the year before the report to a 5-year horizon.

These figures were compared with those from other reports, notably from Ericsson (Ericsson Mobility Report, 2015, 2016, 2017, 2018, 2019, 2020), the ITU (ITU-R, M2370.0, 2015), the Borderstep Institute for Innovation and Sustainability (2019, 2020) and the IEA-EDNA (Intelligent Efficiency For Data Centres & Wide Area Networks, 2019).

- **Terminals production phase**

In order to update the terminals production data, we have relied on figures published quarterly by Gartner and the International Data Corporation (IDC), and the statistics website Statista[7].

- **Global electricity consumption**

We have updated the overall electricity consumption statistics (all sectors) from the International Energy Agency's Headline Energy Data 2018 (IEA) and its projections (World Energy Outlook, 2019).

Finally, we have updated the projections of the evolution of global digital impacts, using our full model to a 2025 horizon[8] based on four new scenarios.

3. Four new evolutionary scenarios

We have defined four new scenarios for our simulations up to 2025. They are essentially defined by assumptions about the two following dynamics:

- **The annual growth rates of digital 'volumes'** (device production, network traffic, data centre traffic) which are indicative of the evolution of uses,

[7] https://www.statista.com

[8] The description of the scenarios developed in 2018 is available in the appendix.

- **The annual decrease in energy intensity ratios** (unit electricity consumption of equipment, network and data centre consumption per unit of traffic), resulting from technological and industrial progress.

They can be summarized as follows:

- **"Conservative"**: we have maintained the same rate of energy efficiency gains as historically observed from 2013 to 2019 and have updated the traffic data only on the basis of the figures provided by Cisco, with a significant downward adjustment for mobile traffic, taking into account other sources (Ericsson).

- **"Growth"**: we have kept the same pace of energy efficiency gains as historically observed until 2019 and we have updated traffic data based on historical data provided by Cisco, but have adjusted the forecast to 2025 to take into account that the historical growth rate turned out to be higher than Cisco's (and, for mobile traffic, Ericsson's) past forecasts.

- **"Growth less EE"**: a variant of the previous scenario, this takes into account a (slight) slowdown in energy efficiency gains in data centres from 2020 onwards, due to the rise of edge computing[9] and within networks (especially mobile) due to the increase in site density, linked to the upgrade of frequencies.

- **“New Sobriety”**: this scenario assumes less growth in the production of new types of equipment (IoT modules, video accessories, etc.) as well as traffic (control of video uses and Artificial Intelligence applications). The energy efficiency gains are the same as in the first two scenarios. While this scenario shows a significant break in digital consumption patterns and enables GHG emissions to be stabilised, on its own it is not enough to align the digital sector with a +2°C trajectory. It must therefore be accompanied by a prioritization of digitization projects enabling reduced emissions from other sectors (including mobility).[10]

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[9] "Edge Computing is an open distributed computing architecture that features decentralised processing power enabling mobile computing and Internet of Things (IoT) technologies. Data is processed by the device itself or by a local computer or server instead of being transmitted to a datacenter. " (HPE, 2018, www.hpe.com/fr/fr/what-is/edge-computing).

[10] Selecting the innovations that are truly relevant to the decarbonization of other sectors requires systemic thinking across different sectors of the economy. This is the method developed and implemented within the plan to transform the French economy elaborated by The Shift Project (The Shift Project PTEF, 2020) announced in May 2020 (https://theshiftproject.org/article/crise-climat-plan-transformation-economie-chantier-urgence-crowdfunding/).

Scenarios	Energy efficiency	Data traffic	Equipment Production[11]
Conservative	Historical pace	Moderate pace	Moderate pace
Growth	Historical pace	Rapid pace	Rapid pace
Growth less EE	Slight slowdown	Rapid pace	Rapid pace
New sobriety	Historical pace	Deceleration	Deceleration

Table 1: Description of the Forecast Model 2021 scenarios

(assumptions different from the historical rate are applied to the period 2020-2025 only)

(The Shift Project, Forecast Model 2021)

C. The problematic growth in energy consumption

The report shows that the **final energy consumption** of the global digital sector is increasing by approximately **6.2% per year** (2015 to 2019). **This growth rate corresponds to a doubling every 11 years** and is bound to increase in all scenarios that do not include a voluntary change in consumption practices (traffic, terminals).

Final energy consumption (in TWh)	2015	2019	2025	CAGR[12] 2015/2019	CAGR 2019/2025
Conservative	3,289	4,181	6,041	6.2%	6.5%
Growth			6,860	6.2%	8.6%
Growth less EE			7,335	6.2%	9.8%
New sobriety			4,209	6.2%	0%

11 For hardware, the difference in pace between the Conservative scenario and the Growth scenarios only applies to terminals whose markets are emerging.

12 Compounded Annual Growth Rate. E.g.: a sum that goes from 100 to 121 in two years has grown (CAGR) by 10% per year.

Table 2: World final energy consumption of digital technology in TWh (The Shift Project - Forecast Model 2021)

As far as primary energy consumption is concerned, our new simulations confirm our previous results: the share of digital technologies in primary energy consumption (itself growing by 1.5% per year) could double during the next 10 years to over 9%; **it is already over 5% in 2020.**

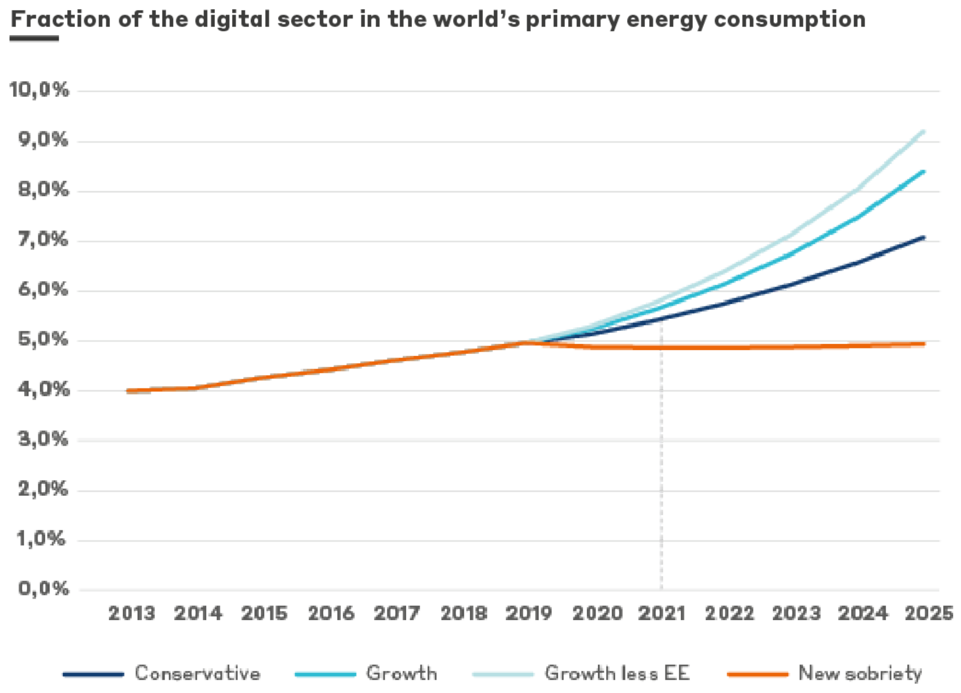

Figure 1: Evolution 2013-2025 of the share of digital technologies in global primary energy consumption (The Shift Project - Forecast Model 2021)

For the 2020 to 2025 period, comparing different scenarios shows the emergence of separate trajectories:

- **A continuously observed** growth **even when the energy efficiency trend is extended** (networks and data centres) and the assumption of a consumption growth slowdown (traffic, terminals) is realised. This leads to a ratio of over 7% of the global primary energy consumption in 2025, comparable to 60% of the primary energy consumed by the European Union in 2019 (BP, 2020). > Scenario "conservative"
- **An acceleration** of the latter[13] **if growth of uses does not slow down**. If energy efficiency progress decreases[13] even slightly, digital could account for more than 9% of

[13] This risk is real because current technologies are approaching their limits and future technologies (e.g. quantum processors) will not be industrialised by 2025 (or even 2030).

primary energy consumption in 2025, or 25% of the energy consumed by OECD countries (BP, 2020). > Scenario "Growth less EE'

- **A stabilisation** of digital technologies energy consumption **if we manage to control our consumption practices** (more selective video usage, longer retention time for smart-phones, prioritisation of IoT use cases, etc.). Under these conditions, primary energy consumption does not increase and the ratio remains at around **5% until 2025**. However, **this scenario does not in any way constrain the digital transition**: growth in traffic remains very high (14% in data centres, 23% on mobile networks) and the number of connected objects (IoT modules) increases by 10% per year. > Scenario "New sobriety"

D. The global digital carbon footprint

While considering the evolution of the carbon intensity of global energy (and electricity) production, we estimate that the share of **greenhouse gas (GHG)** emissions related to digital technology has increased from **2.9% in 2013 to 3.5% in 2019** (1.84 Gt).

GHG emissions in GtCO2eq	2015	2019	2025	CAGR 2015/2019	CAGR 2019/2025
Conservative	1.5	1.8	2.4	6%	4.7%
Growth			2.8	6%	7.3%
Growth less EE			3.1	6%	8.8%
New sobriety			1.7	6%	-1.4%

Table 3: Global GHG emissions related to digital technology in GtCO2e. (The Shift Project - Forecast Model 2021)

This figure is slightly lower than our estimate made in 2018 (around 2.1 Gt) but it is still in the same ballpark as those related to sectors known for a much larger carbon energy consumption and material footprint: the share of GHG emissions from light vehicles (cars, motorcycles, etc.) was around 8% in 2018, and the one from civil aviation was around 2.5% in 2018 (The Shift Project, 2020b).

Even more worryingly, the **GHG emissions growth rate due to digital technology is around 6%p.a. today**, with a risk of reaching up to 9% p.a.in the short term. Thus, this growth must be analyzed by taking into account the GHG emission reduction goals as defined during COP 21 and reaffirmed by subsequent IPCC and UNEP reports. These reports clearly indicate that annual fossil CO2 emissions must be halved by 2030 to preserve chances of keeping global warming below 2°C. While we can therefore hope for a gradual decrease in total GHG emissions in the short term, **the share of these emissions coming from digital technology will continue to increase and could double and exceed 7% by 2025**.

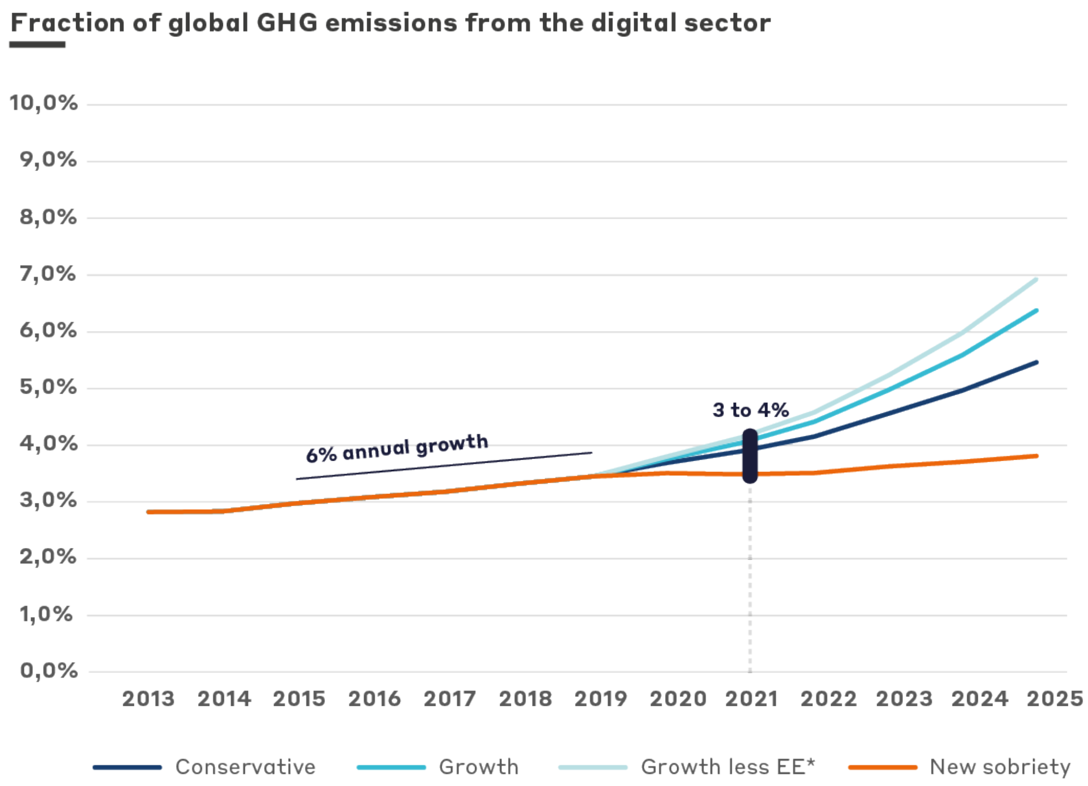

Figure 2: 2013-2025 evolution of the share coming from digital technology in global GHG emissions (The Shift Project - Forecast Model 2021)

Carbon footprint distribution between production and use phases

The hardware production phase is a very significant part of the total carbon footprint of digital technology, making up nearly 40% in 2019,

Additionally, this becomes the major element of the carbon footprint of those hardware assets which integrate a large number of functionalities and are used in an intermittent way. Thus, 80% of the carbon footprint of a smartphone, used for two years, is generated before its first minute of actual use.

An important part of the environmental challenge for digital technology does not therefore relate to how it is used but to the volume of digital equipment that is produced, the production process, and the lifespan of the assets.

At the scale of a country like France, benefiting mainly from low-carbon electricity, emissions from manufacture can exceed 80% of the total footprint coming from digital technology (Senate - Citizing - Virtus Management, 2020).

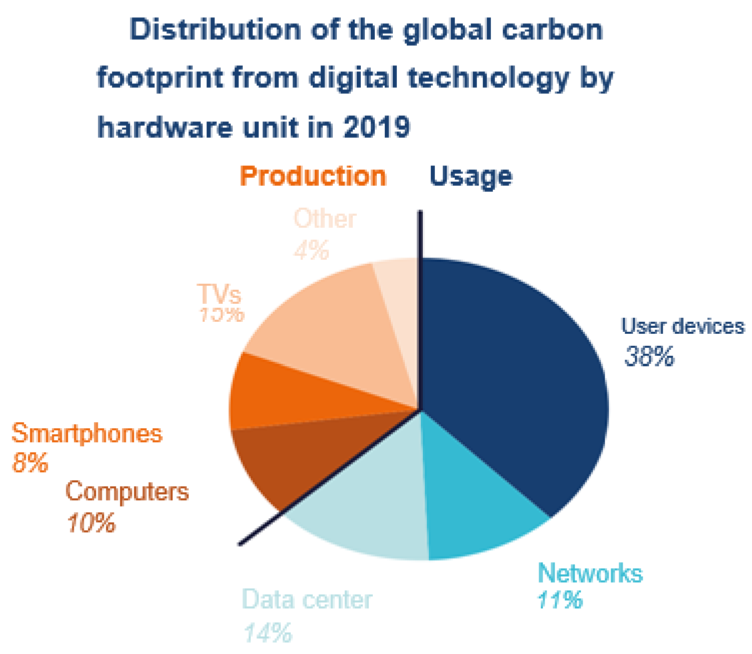

Figure 3: Distribution of the global carbon footprint from digital technology by hardware unit in 2019 (The Shift Project - Forecast Model 2021)

E. Comparison with 2018 results, consequences and conclusions

Final energy consumtion consumption	Share of 2019 global consumption	Annual evolution of consumption (2015-2019)	Share of 2025 global consumption
2018 model	3.1% (Expected updated)	+ 9%/year	4.7 to 6%
2021 update	**3.6%**	**+ 6.2%/year**	**4.8 to 5.9%** (excluding New Sobriety)

Table 4: Global digital energy consumption - comparison of results updated with 2018 results (The Shift Project - Forecast Model 2021), (The Shift Project - Forecast Model 2018)

Carbon footprint	Share of 2019 global emissions	Annual evolution of emissions (2015-2019)	Share of 2025 global emissions
2018 model	4.0% (Expected updated)	+ 8%/year	6.9 to 8.8% (excluding Sobriety)
2021 update	**3.5%**	**+ 5.5%/year**	**5.5 to 6.9%** (excluding New Sobriety)

Table 5: Global digital carbon footprint - comparing updated results with 2018 results (The Shift Project - Forecast Model 2021), (The Shift Project - Forecast Model 2018)

The annual evolution of digital technology's **global final energy consumption** shows a slightly lower trend than the one our 2018 model predicted. Nevertheless, this remains higher than the "expected case" average scenario forecast by Andrae and Edler (+ 4%/year) in 2015[14].

[14] Details on these scenarios are available in the appendix.

Regarding the carbon footprint, if the assessment of current annual emissions turns out to **really be around 3.5% of global emissions,** the projections of our updated model are slightly lower than those of the 2018 model(5.5 to 7% in 2025 instead of 7 to 9%).

This reassessment does not change the orders of magnitude of the impacts of digital technology, either today or by 2025. This consolidation shows that **these trends remain unsustainable and incompatible with the Paris Agreement goals.** *The Shift Project therefore confims and reasserts its* recommendations to regain control over the evolution of this footprint.

II. Digital growth dynamics

The causes of the growth in high energy consumption by digital technology are numerous, but it is possible, at first glance, to identify **5 main factors**:

- The video (streaming) boom and its consequences: TV, advertising screens, large monitors;
- Assisted comfort technologies: connected speakers, home security cameras, etc.;
- The global universalization of smartphones;
- The booming of IoT and IIoT;
- Growing needs of data processing and transfer are not compensated by technological progress:
  - The explosion of mobile data traffic,
  - The demand for computing capabilities (AI, crypto currencies),
  - Edge computing.

A. Exploding data volume

The **growing number of users** equipped with at least one connected device (mainly a smartphone, especially in developing countries), the increased **number of connected devices per person** (from 2.1 in 2015 to 3.6 in 2023 as a global average), **increased video traffic** coupled with the growing share of images in HD and UHD quality as well as use changes towards **on demand consumption** (streaming, VOD, cloud gaming)[15] are all factors causing an explosion of network traffic (more than 26%

[15] The proportion of UHD televisions will increase from 15% of the overall installed base in 2016 to 56% in 2021 (Cisco, 2017a).

per year (Cisco, 2018a)) and data centers (+ 35% per year, (Cisco, 2018b)). This growth is occurring at a rate surpassing the energy efficiency gains of hardware, networks, and data centers. These traffic forecasts are also **regularly revised upward**.

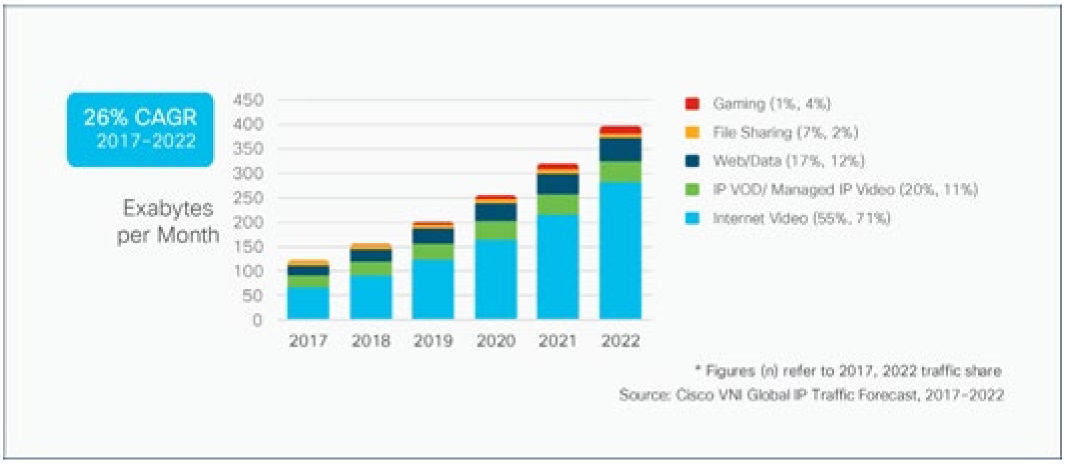

Figure 4: Evolution of traffic shares 2017-2022 (Source: (Cisco, 2018a))

Most data flow growth is attributable to consumption of services provided by the "GAFAM"[16], to the point where this growth can represent up to 80% of network traffic of specific operators. This increased traffic is coupled with an even more significant increase in the volume of data stored in data centers, driven by "Cloud" and "Big data" approaches: + 40% per year, meaning 1 Zettabyte in 2020 (Cisco, 2018b).

Data stored in data centers therefore now represents 20% of the volume of data (5 Zettabytes) stored on terminals, versus 14% in 2015, which contributes to growing traffic. Note that Cisco estimates the volume of "useful" data generated by the IoT and IIoT approaches to be around 67 Zettabytes in 2020, i.e. 35 times more than the expected storage capacity in data centers at this time. **To ensure the full effectiveness of currently implemented "Cloud" and "Big data" approaches, it will therefore be necessary:**

- To implement **new architectures that transfer data processing and storage capabilities as close as possible to sensors** so that services based on IoT and IIoT can effectively be developed (edge computing, fog computing[17]*)*. This should lead to additional growth of the installed base of active devices, as well

[16] Google, Apple, Facebook, Amazon, Microsoft, to which we are more and more adding their Chinese counterparts Baidu, Alibaba, Tencent, Xiaomi (BATX).
[17] "Edge computing is a distributed, open IT architecture featuring decentralized processing power, enabling mobile computing and Internet of Things (IoT) technologies. In edge computing, data is processed by the device itself or by a local computer or server, rather than being transmitted to a data center." (HPE, 2018, https://www.hpe.com/us/en/what-is/edge-computing.html). Fog computing brings the processing capabilities of data even closer to its point of origin, by integrating any connected device into the infrastructure.

as increased energy expenditure via the decentralization of artificial intelligence units and the multiplication of aggregation-layer-based data centers.

- To develop **additional storage capacities** based on SSD technology[18] (especially 3D NAND[19]). This will lead to increased energy intensity of these devices stemming from the manufacturing phase.

Note as well that **growth is so fast that questions arise regarding the ability to ensure sufficient industrial production of storage equipment** (Techradar, 2015).

Despite the fact that hyperscale data centers, with much better energy efficiency than traditional data centers, absorb an increasing portion of global traffic (around 50% in 2020, and nearly 2/3 in 2025) and of the related IT load, the electric consumption of data centers is increasing. This is particularly driven by edge computing deployment from 2020 onwards and **the rise of crypto currencies** such as Bitcoin.

Bitcoin, based on a so-called “proof of work” verification approach, requires the execution of complex computations, the level of difficulty of which is in a way the guarantee of the transaction security. This level of difficulty is regularly raised since the resolution speed of the algorithms increases according to the computing power dedicated to this resolution, computing power which is itself boosted by the rise in prices and the hope for profits from “miners”. A race for computing power follows, which, even when using processors designed specifically for this type of use, results in a massive increase in electricity consumption.

According to the Cambridge Observatory (Cambridge Center for Alternative Finance, 2021), yearly electricity consumption required by Bitcoin in March 2021 was around 130 TWh and **increases by about 40% per year**. Although part of this consumption is due to individual miners working in network to share the computing power of their servers, the main part of the computations (more than 2/3) is taking place within “dedicated farms” (crypto-mining farms) (Stoll, C. et al., 2019). Based on a consumption of around 70 TWh in 2020, we can therefore estimate that Bitcoin already contributes up to 10% of the total consumption of data centers (45 TWh out of 438 TWh) and is one of the main increasing factors in this area.

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[18] SSD or Solid-State Disk or Flash memory: the storage is carried out on computer chips.
[19] NAND: type of Flash memory technology

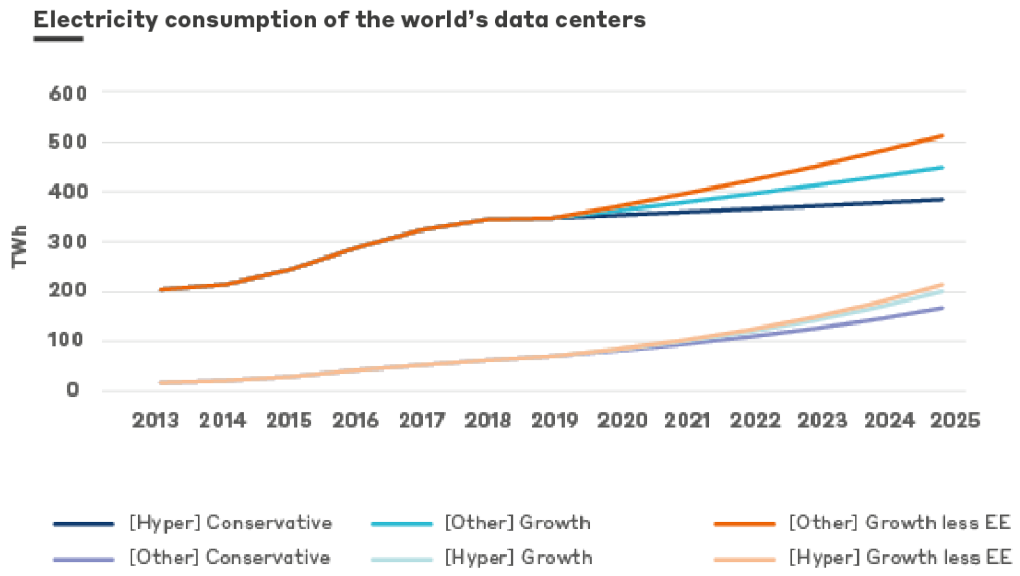


Figure 5 - 2013-2025 evolution of the power consumption of data centers around the world.
"[Hyper]" prefixes: consumption scenarios for "hyperscale" data centers
"[Other]" prefixes: consumption scenarios for other data centers

B. The rise of connected terminals

1. The smartphone phenomenon

Not only is the fleet of smartphones rapidly growing (4 billion in 2017, 6.7 billion in 2023, i.e. 9% per year (Cisco, 2020)), but the abundance of smartphone features continues to increase. This results in greater energy consumption during their production, in particular due to the extraction of metals, which are increasingly diversified.

The energy consumption of terminals in use also increases because more applications are being used; a visible sign of this latest trend is the smartphone reloading frequency, which remains roughly constant while the average battery power has increased by 50% in 5 years.

Although this last phenomenon is an outstanding example of the rebound effect, most of the energy consumption remains in the production phase: 90% versus 10% for its use, according to synthetic data from the Référentiel Environnemental du Numérique (Digital Environmental Datum) (The Shift Project, 2018).

However, sales volumes (1.4 billion units in 2018) are not only driven by the gradual equipment of developing countries but also by "inflationary" consumption habits in developed countries (frequency of renewal shorter than 2 years). These are partly fuelled by a, more or less, planned obsolescence (successive versions of operating systems are only compatible with terminals of previous generations at the cost of degraded performance and/or a significant reduction of useful battery capacity), and by technological changes of generation as well. Smartphone sales, which had slowed down in recent years, have started to increase again at the end of 2020 with 5G's expansion, and are expected to grow by 3.5% per year until 2025 according to IDC.

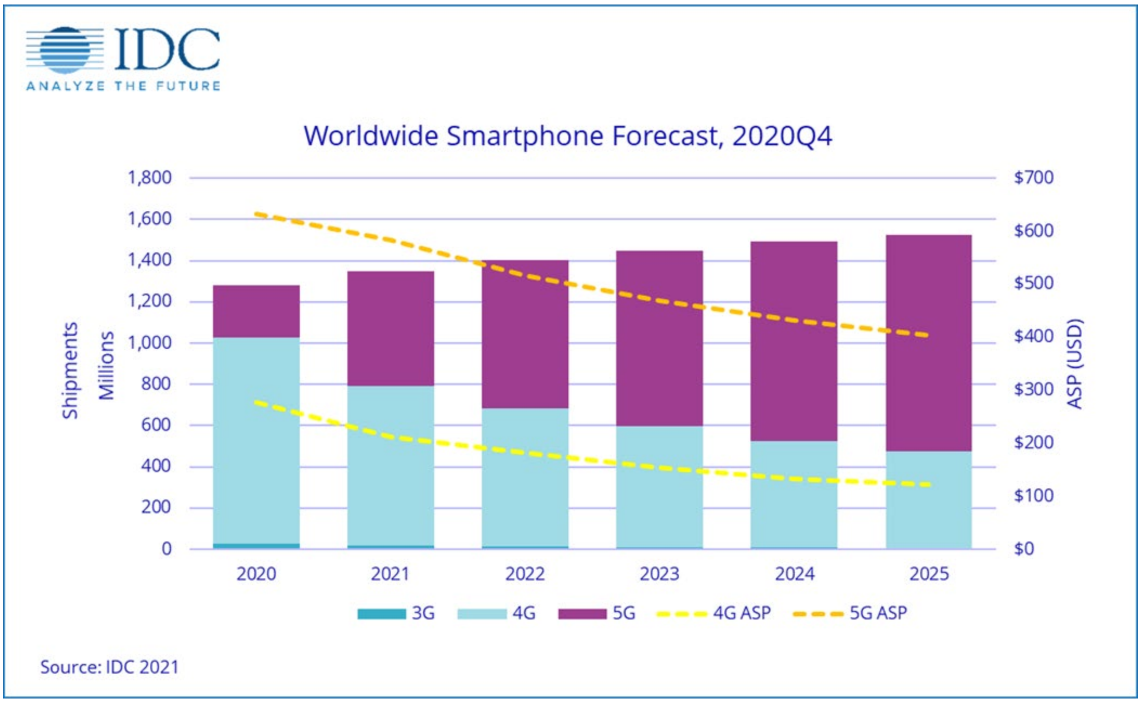


Figure 6: Projection of annual smartphone production and evolution of the average price of a smartphone (Source: IDC)

The Internet of Things (IoT) and the proliferation of connected equipment for everyday life

New devices are appearing (bracelets measuring physical activity, portable Bluetooth speakers, etc.) and existing appliances in all homes become smart (televisions, refrigerators, coffee machines, alarm and surveillance systems, thermostats, lighting etc.). This trend is so strong that it is expected to double the number of digitally connected devices in the next decade (see Figure 8 below).

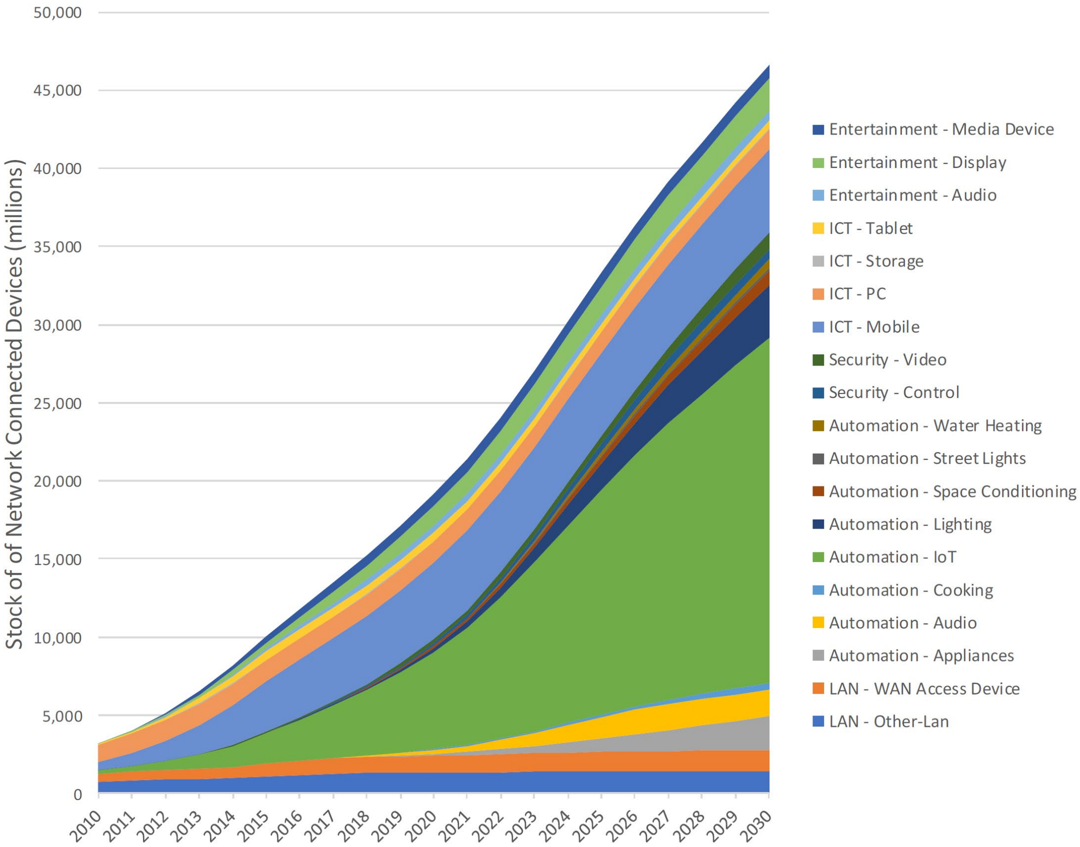


Figure 7: Stock of connected devices evolution around the world (Source: (IEA 4E EDNA, 2019))

This spread of daily connected appliances, however, occurs mainly in developed countries and thus leads to an increased digital gap with the rest of the world: while the rate of equipment is actually increasing in all regions, the growth in the equipment rate expected from 2018 to 2023 in the already over-equipped developed countries should however be much higher than that of the developing countries: + 75% in the United States against + 30% for the African continent, thus emphasizing the already considerable existing gap.

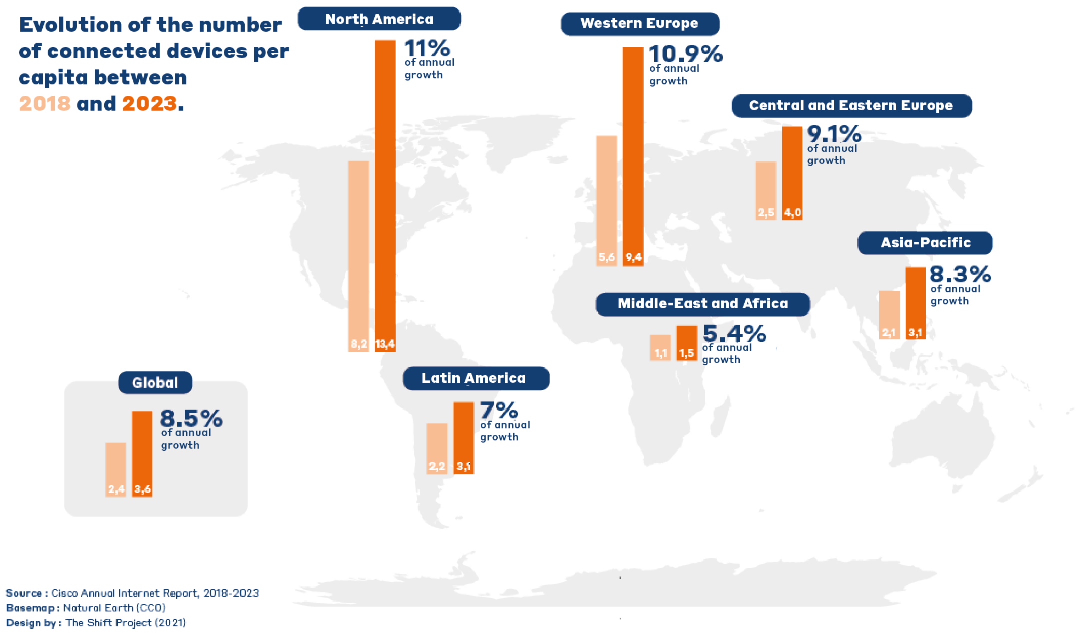


Figure 8: Number of device per capita (Source: Cisco, 2020)

Digital equipment in a 4-person household in an OECD country

2012	2017	2022
2 smartphones	4 smartphones	4 smartphones
2 laptops / computers	2 laptops / computers	2 laptops / computers
1 tablet	2 tablets	2 tablets
1 DSL/Cable/Fibre/Wifi Modem	2 DSL/Cable/Fibre/Wifi Modem	3 DSL/Cable/Fibre/Wifi Modem
1 Printer / scanner	1 Printer / scanner	1 Printer / scanner
1 Game console	1 Game console	1 Game console
	1 connected television	3 connected television
	2 network attached storage	1 network attached storage
	2 eReaders	2 eReaders
	1 smart metre	1 smart metre
	2 connected stereo systems	3 connected stereo systems
	1 energy consumption display	1 energy consumption display
	1 Internet connected car	2 Internet connected car
	1 pair of connected sport shoes	3 connectes sport devices
	1 pay as you drive device	2 pay as you drive devices
		1 digital camera
		7 smart light bubles
		5 internet connected power socker
		1 weight scale
		1 eHealth device
		1 intelligent thermostat
		4 home automation sensors

Figure 9: Digital equipment in a 4-person household in an OECD country (Source: (GSMA, 2015))

2. Rise of the IIoT (Industrial Internet of Things)

The Industrial Internet of Things (IIoT) consists, through on-board technology (sensors, actuators, RFID chips, etc.), in identifying and enabling communication between all value chain links (machines, products being built, finished and in use, employees, suppliers, customers, infrastructure, etc.), which can be referred to as “things”.

Connected things then make it possible to collect information - which until now was only provided by manual human actions - in the form of data, that can then be stored and analyzed. This is one of the technological pillars of 4.0 Industry, with robotics and artificial intelligence.

IIoT leads companies to make significant investments in communicating digital technologies (in the order of $965 billion in 2017, with a strong growth of around 21% per year) (Gartner, 2017). According to Gartner, the number of communication interfaces of this type will increase by 55% per year until reaching 7.5 billion in 2020 (Gartner, 2017).

C. New networks for these new services

The growth of connected terminals, and the uses stemming from it, increases data generation, storage and processing. Thus the dynamics described here generate a continuous need to increase the capacity of our network infrastructures. This movement is reflected on the one hand, by the replacement of copper fixed access networks by optical fibre networks, and, on the other hand, by the simultaneous use of new generations of mobile telecommunications and of higher and higher frequency bands.

While the replacement of "copper" networks by fibre optic networks is undoubtedly beneficial in terms of energy consumption, the same would not apply to mobile networks.

The annual growth rate of mobile traffic (more than 60% over the past 5 years), the increase radio sites density made necessary by the rise in frequencies (the higher the frequency used, the shorter the signal range) and the coverage of new territories to reduce digital gaps have led to an increase of 25% per year in their electricity consumption since 2015, despite massive energy efficiency gains of around 20% per year. The consumption of mobile networks thus became greater than the one of fixed networks as of 2018. If traffic growth slows down considerably (37% per year in our “conservative” scenario close to Ericsson's posted forecasts), electricity consumption will “only” increase by 10% per year. But, if it remains at a higher rate (50%, i.e. the average assumption appearing in the ITU scenarios), electricity consumption will continue to grow at a rate close to 25% per year.

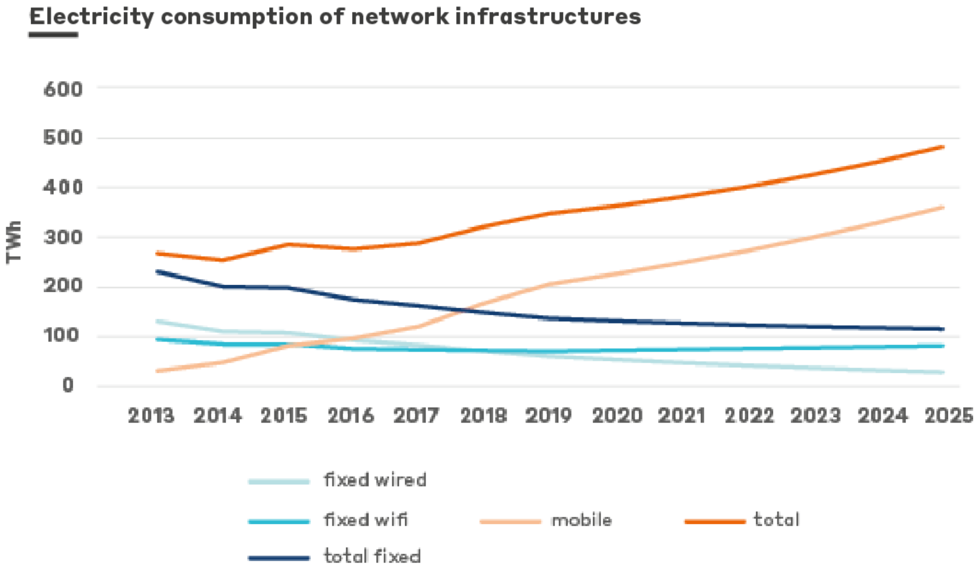
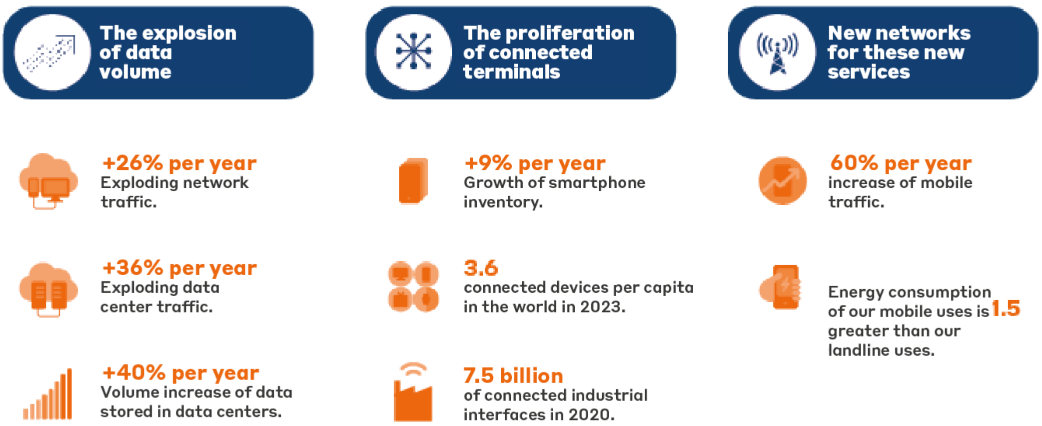


Figure 10: 2013-2025 change in electricity consumption by networks around the world (Conservative scenario) (The Shift Project - Forecast Model 2021)

Global energy consumption associated with our mobile uses is already 1.5 times greater than our fixed uses. They are thus at the heart of the challenges posed by unsustainable trends already identified in 2018 (and confirmed in this update), and yet these trends are today the motivation to deploy our 5th generation of mobile networks.

02- 3- The dynamics of digital growth - Figures to remember



03

5G: QUESTIONS ARE STILL PENDING

I. The digital system will not automatically become sustainable

It is undeniable that if we do not implement the means to manage it, the impact of digital technology will only increase, as will the footprint of the rest of the economy. For several decades, the technological improvements that have enabled a per unit decrease in the energy consumption of our devices and networks have systematically been offset by evolutions of our technology use [20]:

- We produce more and more devices
- The amount of equipment for individuals and households continuously increases,
- Our uses are more and more data intensive,
- Our uses are increasingly mobile and so rely on mobile networks which consume more than landline networks (4G instead of Wi-Fi for example)

Historically, technological progress has never reduced the overall environmental impacts of our digital system (taking into account global production and use phases of our equipment).[21]

Questioning the place of networks in the race to achieve the 2°C pathway means steering our networks and our digital uses towards basis which considers these facts more rationally.

A. The evolution of our networks: a story of uses

Future networks must evolve jointly with and be built around our use choices rather than driving these. It is new services and their growing use that should motivate and justify the deployment of new capacities for our networks, whose availability will in turn lead to the emergence of new uses.

[20] As developed in the prospective scenarios of the previous part of this note.

[21] However, in the context of the energy and carbon challenges, it is the total quantity of energy (and emissions) that counts: the problem being physical (concretely, the challenge is to emit less CO_2 into the atmosphere), our reflections cannot be confined to relative reasoning that would only embrace a limited scope or direct impacts - as we are reminded in the recent recommendations of the French High Council for Climate (HCC, 2020b).

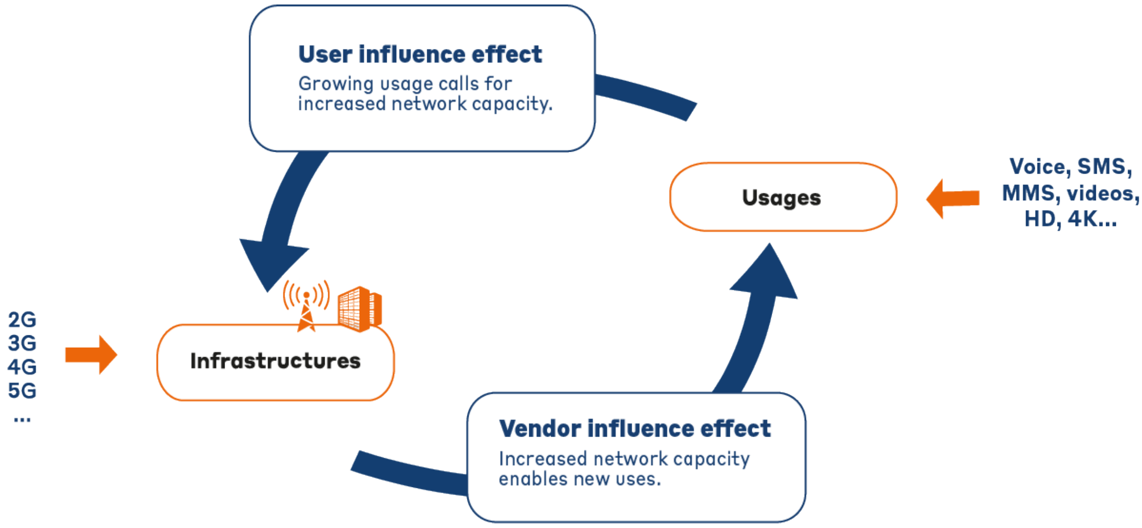


Figure 11: Our uses and our networks are two sides of the same coin (Source: The Shift Project, 2020)

Believing that our uses evolve autonomously and endogenously, or "naturally", is a strategic error. We are currently developing our network infrastructures as if the role of our digital governance was limited to managing the consequences of an automatic growth in uses. However, our governance must include the management of the causes of this growth, the dynamics of which are identified below.

The sociology of uses, the behavioural studies of digital uses and the study of platform designs have shown that if individuals are consuming more and more data, it is not simply "by reflex" but largely because the mechanisms around which our tools are structured are oriented towards this[22] (The Shift Project, 2020). The main element guiding our infrastructure deployment since the 2000s (coincident with the rise of GAFAM[23] and datacentric economic models) is the necessity to make new connected services available, in particular those introduced and promoted by US actors and their counterparts (The Shift Project, 2019).

The profitability of these services, built on the monetization of data volumes and the sale of goods and connected devices, leads to a constant increase in infrastructure requirements such as: available speeds, simultaneously connected objects[24], ubiquitous connection in public spaces, etc. (The Shift Project, 2020)

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[22] The presentation modes of platforms, applications and social networks content use cognitive mechanisms and biases to maximize the quantity of content consumed by users (autoplay or infinite scrolling, notifications etc.): this is often referred to as addictive designs.

[23] Google, Amazon, Facebook, Apple, Microsoft

[24] Connected objects are essentially sensors: they allow data acquisition, sometimes for direct use (such as a presence sensor), but almost systematically with a data concentrating and processing system for indirect use (for example via connected assistants such as Alexa or Google Home).

Uses based on mobile infrastructures are above all ambulatory uses. . Thus, the deployment of mobile infrastructures serves primarily the development of this category of services and activities, which do not rely on fixed access offers such as those enabled by fibre connected households.

It is this family of uses that has developed jointly with the appearance of successive generations of mobile networks[25]:

• 2G, deployed in the 1990s, notably enabled the first digital mobile transmissions for voice and text messages (SMS);

• 3G, deployed in the 2000s, notably enabled mobile uses linked to Internet browsing, such as viewing images or even low definition videos;

• 4G, rolled out in the 2010s, enabled generalizing connected mobile uses, such as viewing HD video or using a mobile terminal as an access point.

Each generation of mobile networks comes with an increase in the data intensity of mobile uses: on one hand because it happens simultaneously with the appearance of new, more powerful terminals, but also because it enables much more byte-intensive services for an equivalent terminal (Cisco, 2019). However, as we have seen, due to the absence of a substitution effect between networks[26], higher consumption of mobile networks compared to landline networks[27] and rebound effects[28] ,total digital use consumption has been constantly increasing for several decades despite very significant technological improvements in per unit energy efficiency across network generations.

There is no objective reason why 5G would produce different effects from previous generations if its management and profitability drivers remain the same. Our digital governance must therefore take into account digital technology business models enabling compatible profitable developments and climate change constraints.

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[25] This summary presents a schematic synthesis of the succession of the different generations and associated functionalities, by smoothing out the details of the generations/intermediate versions.

[26] Since 2G and so far, the deployment of an additional generation of network has not resulted in eliminating an older one. (Prison, T., Dekimpe, R., 2020).

[27] cf. previous part of this report.

[28] Recent academic work confirms that digital technologies performance gains continue to be fully absorbed by rebound effects (Bol, D. Prison, T., Dekimpe, R., 2020).

B. Panorama of the 5G debate: politicization but polarization

1. Technology is a political issue

Technology engages certain societal choices and is thus, de facto, a political issue. The digital system behaves like any other system in that it has its own dynamics and interacts with other subsystems of our economy[29]. Thus, deploying a service or a connected infrastructure in a territory means choosing to develop specific dynamics, which will influence those already in place and condition those that can be developed later (The Shift Project, 2020).

Since the challenge of this decade is to seize our last chance at resilience, we must make digital technology the positive tool and asset it can become. We can, nowadays, understand its dynamics and the implications of our technological choices on other elements of society. It is therefore urgent and essential to integrate these dimensions in its management.

2. The 5G debate in France

The 5G debate, which is the demonstration of a concrete entry of technological issues into public discussion, was built in 2020 around the question of the moratorium. The discussion around a moratorium is not synonymous with a position “for” or “against” the technology in itself: it only aims to allow for evaluations of the relevance of an infrastructure to be carried out before its deployment.

The public consultation procedure on the challenges of 5G was initiated several years ago, with among others the public consultation of Arcep "New frequencies for territories, companies, 5G and innovation" (Arcep, 2017). Although they are today one of the central elements of any debate on the future of our digital technology, environmental issues were completely absent from the subjects addressed at that time.[30] This was despite the previous existence of studies and organisations working on the topic[31]. The example of state of these debates in France during 2020 demonstrates the inability of our current digital governance mechanisms to implement the supported and collective management that The Shift Project and other actors advocated for in

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[29] Services resulting from a fundamentally digital ecosystem (such as self-driven cars, bicycles, electric scooters, delivery, connection for purchases or rental of housing, etc.) had and continue to have dimensioning impacts on the forms our systems take - and may take in the future: food, mobility, mass consumption, town and regional planning, etc.

[30] The launch of the “For a sustainable digital” approach by Arcep in June 2020. https://www.arcep.fr/nos-sujets/numerique-et-environnement.html, https://www.arcep.fr/actualites/les-communiques-de-presse/detail/n/environnement-151220.html.

[31] For example, the CNRS EcoInfo service group has existed since 2006, the GreenIT.fr community since 2004, the Fing since 2000, the Green IT Alliance since 2011 etc.

2018 (The Shift Project, 2018), by involving public authorities, regulators, digital services providers and designers, network operators and user communities.

The debate on the moratorium and its results ended up in the deployment of the first building blocks of infrastructure[32], but did not bring answers to the two questions which should structure our choices: the "why" we should deploy 5G and "how" best to do so. Addressing these questions is essential to make 5G sustainable:

- The "why" raises the question of uses and needs that the technology must and can meet once deployed. It is about identifying and quantifying its potential contribution in light of the strategic objectives that motivate its deployment.

- The "how" asks the question of the terms of any deployment (which territories, at which service /density levels, etc) based on its relevance. The deployment chosen should at least enable effective carbon footprint and energy consumption reductions within the concerned activities and territories.

II. 5G: Just one building block of a structure that must contribute to resilience

A. Impacts will inevitably worsen in the absence of regulation

Studies from several organizations concur that, if it goes ahead, an unregulated, dense and broad roll-out of 5G networks will considerably increase energy consumption and emissions from digital activities. This position is held consistently across public (French High Council For Climate, HCC2020a), service provider (GSMA, 2019a) and equipment vendor (Huawei, 2020) organizations.

[32] Following the auction for the allocation of the 3.4 - 3.8 GHz band, finalized in November 2020 (Arcep, 2021).

According to the French High Council for Climate, **5G roll-out will lead to an 18-44% increase of the digital sector carbon footprint by 2030** (HCC, 2020a) (Citizing - Virtus Management, 2020). According to the GSMA, **in spite of an improving per unit energetic efficiency**, operator costs due to **energy consumption** will see a double-digit percentage increase and **could even be multiply by two or three**.

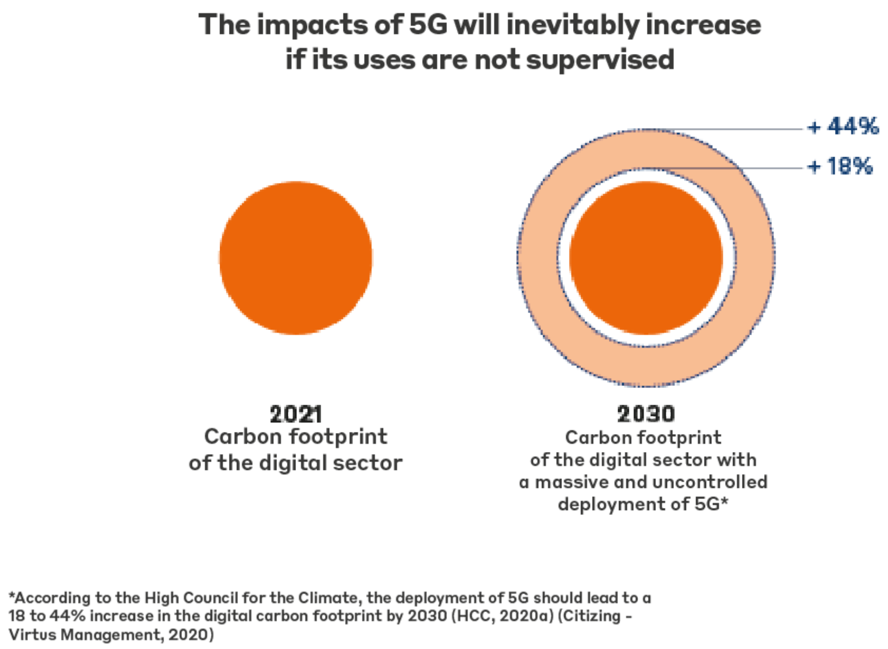

Figure 12: Rising impacts are inevitable in the absence of regulations

This increase is ascribed to the construction of a new network, its usage, and sales of digital devices (HCC, 2020a)[33]. Because this increase moves the digital sector farther away from its resilience targets, **it is important to understand two points**:

- The additional carbon budget (and additional energy) allocated to this new generation of digital uses must be compensated by a reduction of carbon budgets assigned to other sectors (such as transportation or agriculture)[34].

[33] The manufacturing stage of digital devices and network infrastructures accounts for 60% of global digital carbon impact (see supra), and about 70% of the 5G carbon impact to come in France (HCC, 2020a).

[34] Historically, the increase of global digital carbon footprint never went hand-in-hand with a reduction footprint of the rest of the economy (see supra). As a consequence, it is not possible to assert at this stage that positive effects of the digital transformation on the economy shall offset its own environmental impacts in any way (HCC, 2020a).

- Consumption of this additional carbon budget must be justified by the societal relevance of the new services provided, particularly given the energy and climate stakes[35].

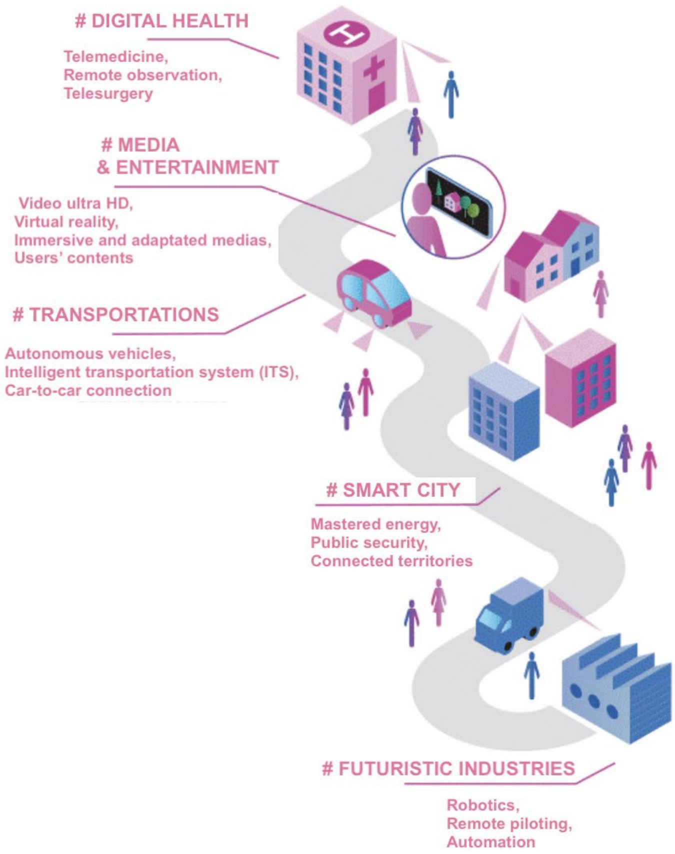

Figure 13 - uses for 5G (Source: (ANFR, 2021))

5G is expected to usher in several new uses (Orange, 2020) (MEFR, Arcep, 2018) (SFR, 2020), each one of them giving rise to questions of practicality and relevance:

- **Videoconferencing**, the generalization of videoconferencing has drastically increased with the health crisis, in particular for essential services such as teleworking, remote learning, medical consultations, etc.. 5G would prevent congestion of the 4G network in

[35] Just as with a constrained economic budget, it is strategically important to make sure that any increase of expenditure is justified.

dense areas but raises the question of upgrading the network in low-density areas as well[36], which could be very costly in terms of energy (HCC, 2020a).

- **Autonomous vehicle technologies** currently being developed require homogeneous and densely meshed connectivity with high capacities for speed and reliability in areas where vehicles will operate. 5G is thought by some players to be the right infrastructure to ensure this level of connectivity in urban settings. However, questions arise relating to the maturity of the technology (in view of the timescale of 5G development), the true contribution of this technology towards a drastic reduction in mobility-related carbon emissions[37], and the true needs for specific infrastructure. Autonomous transportation appears to require capacities for data acquisition, processing, and communication on a very different scale from our current standards[38], calling for a density of network and on-board equipment much higher than today's standards. This again raises the question of our capacity to implement such a large-scale network, and of the carbon impacts incurred by its production and usage.

- **Video surveillance** has also been identified as a development field for 5G by industry players (GSMA, 2019b) (Ericsson, 2018). 5G, which enables higher rates of data transmission and greater numbers of connected objects, could make its general availability possible in public and private spaces. The 24/7 video streams generated would increase traffic handled by mobile networks and data centers.

This list is in no way exhaustive, nor does it claim to give a definitive assessment of the relevance of these digital uses. Decision-making relative to our technological choices must determine the conditions under which to develop 5G, in line with the specificities of the services to be provided. **Our goal here is to show the type of questions which arise if we consider the wider relevance framework.** The next section of this document illustrates this process by further examining two widespread case studies in public debates: private entertainment uses, and specific professional uses such as telesurgery and industry 4.0.

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[36] This issue is of course part of Arcep's 5G roll-out specifications, integrating an obligation for operators to install 25% of 3,5 GHz-bandwidth sites in isolated or industrial areas, away from major cities (Arcep, 2020).

[37] Notably, the need for significantly greater volumes of data could outweigh the benefits of autonomous driving (Gawron, J. H. et al., 2018).

[38] Autonomous driving could, in all likelihood, require data processing rates up to 4 TB/h, partly for the vehicle itself and partly for the network (Intel newsroom, 2017).

B. Uses describing a certain technological and societal future

1. New entertainment options driving unsustainable trends

Private entertainment uses, such as **cloud gaming**[39], **4K video resolution** on mobile devices, and **virtual reality** (VR) could be made possible by 5G infrastructure and drastically increased data rates accessible to mobile devices.

Two main entertainment offers appear to be noteworthy, because of their significant impact on data consumption and usage intensification:

Cloud gaming: the player possesses a device of limited capability (such as a simple gamepad or a mobile phone) and plays a game which is remotely executed in a data center.

Depending on the player's commands (movements of the avatar, for example), the frames are generated by a distant server, then forwarded to the screen via the network. In order to remain undetectable and provide a real-time feel, this method requires both very high speeds and very low latency.

High resolution video streaming promises ever improving resolution and fluidity, including on mobile devices, with 4K on offer today (progressively moving to 90 or even to 120 frames per second), then 8K expected in the short or medium term.

These uses will amplify the trends described in our prospective scenarios, **pushing towards an update of the entire ecosystem** of network infrastructure and equipment, user devices, usages and digital habits:

These uses will extend the trends described by our prospective scenarios by causing a new update to the entire ecosystem, network infrastructures and materials, user equipment and materials, types of uses, and digital habits

- **Smartphone purchases will gather speed once again[40], reversing lifespan improvements made these last few years**, by encouraging consumers to buy devices

[39] A technology exporting data processing capacities to a network cloud, rather than on a game console or a computer. This leads to possible increased processing capabilities, for instance to improve graphics quality, without necessitating powerful user devices, the load being assigned to the network infrastructure.

[40] Refer to the previous section of this report, "The smartphone phenomenon".

with a potentially greater environmental footprint than previous generations of technology[41] (Roussilhe, G., 2020b)

- For cloud gaming providers, building a service meeting demand will require **increased computing capacity and server usage**[42].

- General availability of these mobile uses will change users' habits. **Typically, high-speed connectivity in public transport has become an expectation rather than a high-value service**, increasing network saturation in populated areas.

2. Specific professional uses: easy does it?

Telesurgery consists of enabling surgical operations to be performed remotely, with the surgeon in a different location to the patient and their support team (nurses, anaesthetists, etc.). This could become possible with robots controlled by the surgeon through a highly reliable low-latency connection.

Industry 4.0 refers in particular to the integration of IoT and AI into industry design and production lines. These new technologies would make it possible to optimize and reinvent logistics, production and design processes by greatly increasing the degree of connectivity between value chain components.

These specific professional uses are predicted for wide-scale development thanks to the remarkably low latency of 5G (about 1 ms theoretically) and its ability to manage a large number of connected objects. Two issues arise at this point:

- **The operational feasibility of the use case, beyond technological proof of concept**

- **The deployment method necessary to enable these services** (targeted or nationwide? What density? etc.)

[41] The current fleet of smartphones is generally not compatible with 5G and will need to be replaced. Moreover, the development of more intensive uses such as gaming and very high-resolution video will also lead to increased battery capacity, with impacts linked to their production.

[42] The energy impacts of this effect could be partially offset by a decrease in the number of home gaming consoles.

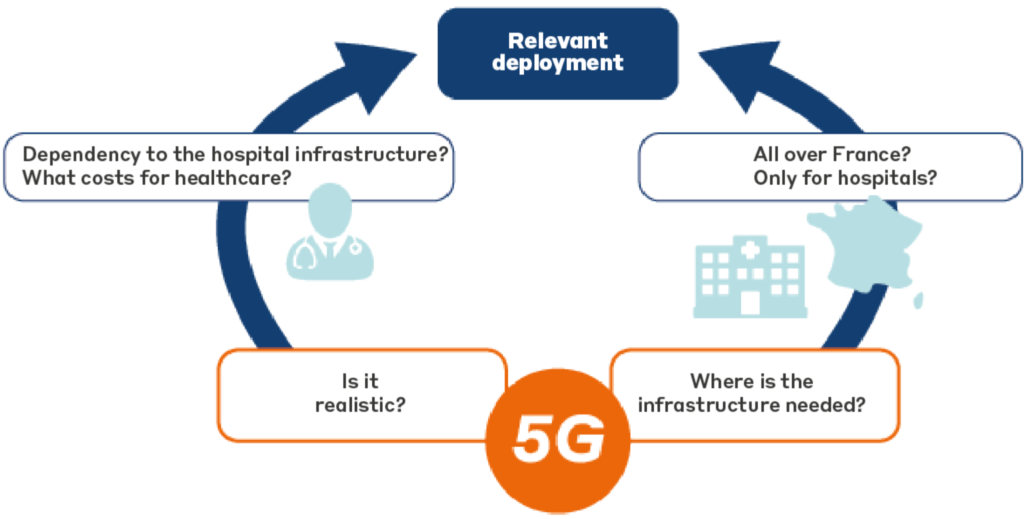

Figure 14 - A first step: gauging infrastructure to optimally respond to a need, before considering it in view of its physical constraints. *The example of telesurgery (Source: The Shift Project).*

It is essential to take into account the operational constraints of use cases in order to assess whether their relevance justifies implementing new infrastructure. For example, the notion that telesurgery will make it possible to receive surgical treatment from one's home or from areas devoid of medical facilities remains unlikely at a large scale. The challenges posed by this use case greatly exceed the opportunities offered by 5G:

- For all but the most benign operations, a loss of connection would endanger the patient's life. A second means of communication (supported by different physical infrastructure) would therefore be necessary for redundancy and continuity of the operation in all circumstances;
- An operation cannot be performed without hospital support. Follow-up care and monitoring still require staff and facilities, and surgeon availability would remain a limiting factor;
- Rural or isolated areas would only benefit from this technology if they were equipped with 5G infrastructure connected to a high-performance network core (such as optical fiber) and had the medical robots necessary for the operation. These are potentially very expensive technologies (SIA Partners, 2019).

Whether it be telesurgery or Industry 4.0, **the approach must be to determine how to ensure truly relevant use cases.** Telesurgery, fascinating and desirable as it is, remains a fixed, hospital-based proposition, just as industrial use cases are bound to production sites. Optimum roll-out conditions must answer the following three questions:

What are the relevant use cases, considering its benefits and operational feasibility?

What prevents the existing communication infrastructure and protocols from meeting these uses? (e.g. the stability of an optical fibre network for telesurgery)

In what areas and for what level of service should 5G be deployed to make these use cases possible? (e.g. restricted to hospitals or industrial sites)

C. Our priority must be to develop a robust network providing access to essential services

It is critical to understand that there is no reason why 5G would produce any different effects to those created by any of the previous generations of technology, unless we implement efficient regulation to incentivize and direct its development over the next 5 to 10 years. Installing 5G networks at a large scale will encourage users towards more massive mobile usage[43], consuming more energy than landline users[44].

If it is to be compatible with our imperatives for resilience, 5G expansion will need to be **selective**[45] and limited to areas and cases where it provides access to relevant services; a "surgical" roll-out for specific uses in the fields of healthcare or industry.

This selection of relevant uses can only be decided by consulting stakeholders, of whom civil society are an integral element. Developing telesurgery and telemedicine uses is not simply a logical step in the drive of technological progress, but a societal choice[46]. This is one of the reasons why the network deployment has raised a vigorous debate, demonstrating the absolute necessity to reimagine our national and European digital governance.

[43] Users with access to a mobile network will tend to stay connected to it by default, even if a landline connection is available (one often keeps one's smartphone connected to 4G even at home, for example).
[44] Mobile networks consume more energy than equal-use landline networks (see previous part of this report on the impacts of global digital technology).
[45] A scenario drafted by the High Council on Climate found a digital carbon footprint 30% lower than that of the "true 5G for all" scenario.
[46] Questions arise - purely by way of illustration - related to the social security model needed for more on-the-go healthcare, for example, or the need for face-to-face care for practitioners and the well-being of patients.

04

CONCLUSION - ACHIEVING DIGITAL RESILIENCE IN EUROPE: WE NEED A PLAN

I. Questions to be answered

Since 5G is going to be available soon, we must address how we should implement it now if we are to build a sustainable digital roadmap. Producing a European digital system that is resilient to the risks of the next 20 to 30 years therefore involves studying the following four major questions:

1. **How are the transformations of other sectors towards a low-carbon economy reflected in digital uses and needs?**
   What availability of services, what priorities, what purchase and post-first life circuits, etc.?

2. **What are the essential uses to preserve in the event of a strong exogenous constraint?**
   Carbon constraint, energy constraint, constraint on raw materials etc.?

3. **What objectives should be given to the digital system to make it compatible with these exogenous constraints?**
   What trajectory should we define and give to the digital system?

4. **How to invent and implement the economic models that will make it possible to structure a digital system that meets these specifications?**
   What objectives, what mechanisms and dynamics, what governance?

II. Actions to be taken

With 5G deployment now confirmed, we need to put in place the right environmental management mechanisms to properly orient infrastructure development. This consists of building, today and in a sustained manner for the decades to come, a governance for our networks based on three components[47] [48] [49]:

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[47] Energy consumption thresholds for infrastructure; annual carbon footprint reduction trajectories for our digital activities (i.e. setting a carbon budget for our digital activities); obligations concerning the direct and indirect emissions avoided so as to reduce the total carbon footprint of activities and of the territory.

[48] These indicators do not yet exist today in a standardized and operational way, although work has been started over recent years, in particular by players such as the French High Council for Climate (HCC, 2020a).

[49] The involvement of local governments during the installation of antennae on their territory, which may be limited to being kept informed of the decision by operators with limited margins to organize consultation, does not yet include the environmental framework (MEFR, 2020). These installations are therefore decided at a national level of governance, making it impossible to assess local needs on a case-by-case basis.

Actions to be taken to make the European digital system resilient

1 Building a new digital governance framework

- **At the national level, creating and harmonizing** decarbonization objectives, quantitative assessment tools
- **At the regional level: giving elected officials the means to consult the public** to decide on priority uses and expansion paths
- **At the European level: developing relevant governance bodies suited to the scale** of the Union's infrastructure, its uses and economic players.

2 Inventing new economic models

- **Leaving behind a model where service profitability depends on massive volumes of data.**
- Making **profitable** uses built on **modularity, reuse and lifespan extension** of terminals, devices, and network hardware.

3 Developing digital management tools

- **Establishing quantified and normative goals for digital technology**, designed to guarantee compatibility with a 2°C pathway.
- Developing **robust energy and carbon impact assessment tools.**
- Developing **monitoring tools** to measure the **effects of digital governance and adjust it** to achieve our goals.

III. Players to mobilize

To implement these actions and a management strategy effectively, the players to involve, challenge and mobilize are:

IV. Building a sustainable digital Europe

Making our digital technology sustainable requires questioning the way in which we profit from and justify our technological choices. The case of 5G has made this clear: new generations of technology can make important innovations possible in certain sectors and for certain essential uses, but these uses are driven by unsustainable dynamics. The relevant and strategic innovations they provide to society depend on massively installed infrastructure.

Building European governance based on essential needs, the physical reality of value chains to be mobilized and the strategic risks of coming decades is the necessary foundation on which to build sustainable and resilient technological choices for our networks.

Questions about Europe's digital model and governance have abounded over the last several years, touching on many subjects such as digital ethics, sovereignty and personal data management. Digital infrastructure and services, now inescapable components of our essential uses (communicating, moving around, governing our democracies, etc.) have become societal subjects that go far beyond the technologies in themselves. However, our current steering mechanisms are not capable of handling questions of this magnitude, as 2020's entrenched debate on 5G demonstrated.

Inventing and putting in place a management system for the environmental impacts of 5G could provide a foundation for a form of governance capable of taking on the challenges of the coming decades. Implementing it within the next three to five years on the 3.5 GHz core bandwidth would give us the means to build informed and deliberate decisions on the 26 GHz bandwidth - with a consolidated strategy, built on the assessment of promising use cases against our resilience objectives and transition towards a carbon-free economy.

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APPENDICES

Description of the 2018 Forecast Model scenarios

In 2018, we defined four scenarios to run our simulations for 2025:

• **“Expected updated”**: we kept the same rate of energy efficiency gains as in the “expected case” scenario, and we updated the traffic data solely on the basis of figures provided by Cisco, extending the trends beyond 2021.

• **“Higher growth higher EE”**: we assumed that energy efficiency would improve more quickly as of 2015 and we updated the traffic data on the basis of historical data provided by Cisco, but applied the historic growth rate to the forecast up to 2025, which turned out to be higher than in the previous scenario.

• **“Superior growth peaked EE”**: this is a variant of the previous scenario, taking into account a slightly higher increase in traffic growth after 2020 and a peak in energy efficiency gains in 2020, especially in data centers. This assumption was based on fears of capping energy performance once all best practices were applied (e.g. United States Data Center Energy Usage Report, 2016, page 47).

• **“Sobriety”**: this was identical to the "Higher growth higher EE" scenario until 2020, but thereafter assuming a slowdown of traffic growth and production made possible by the implementation of sobriety practices. This scenario also included a deceleration of data center energy efficiency gains after 2020 in order to test the robustness of the approach.

The structure of the 2018 model and scenarios was inspired by the model developed by Andrae and Edler in 2015 (Andrae & Edler, 2015), which developed three scenarios for the progression of digital energy consumption from 2010 to 2030:

• The “Best case” scenario: energy efficiency gains (of equipment and of technological platforms) accelerate and traffic growth slows,

• The "Expected case" scenario: energy efficiency gains and traffic growth rate are in line with 2010/2013 historical data,

• The "Worst case" scenario: energy efficiency gains are lower and traffic growth accelerates.

Results of the 2018 Forecast Model scenarios

Final energy consumption (TWh)	2015	2020	2025	CAGR[50] 2015/2020	CAGR 2020/2025
Expected - 2015	2,312	2,878	4,35	4.5%	8.7%
Worst - 2015	3,677	5,976	12	10%	15.5%
Expected updated	2,389	3,834	6,254	9.9%	10.2%
Higher growth higher EE	2,373	3,622	5,716	8.9%	9.5%
Superior growth peaked EE	2,373	3,622	7,096	8.9%	14.5%
Sobriety	2,373	3,622	3,909	8.9%	1.6%

Appendix table 1: Digital final energy consumption in TWh (The Shift Project, Forecast Model 2018)

GHG emissions ($GtCO_2e$)	2015	2020	2025	CAGR 2015/2020	CAGR 2020/2025
Expected - 2015	1.4	1.7	2.5	4%	8%
Worst - 2015	2.3	3.6	8	9%	16%
Expected updated	1.5	2.3	3.6	9.2%	9.9%
Higher growth higher EE	1.5	2.1	3.3	8%	9.2%
Superior growth peaked EE	1.5	2.1	4.1	8%	14%
Sobriety	1.5	2.1	2.3	8%	1.2%

Appendix table 2: GHG emissions in GtCO2e (The Shift Project, Forecast Model 2018)

[50] Compounded Annual Growth Rate, e.g. a quantity increasing from 100 to 121 in two years has a CAGR of 10% per year.

About us

The Shift Project, a carbon transition think tank, aims to tackle the key issues of the carbon transition. Its mission is to provide the factual and quantitative elements that will make it possible to apply the trade-offs necessary for the success of that transition. A key aspect of this is the exponential development of digital technology, and how this interacts with our societies' attempts to decarbonize.

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