-LEAN ICT-

TOWARDS DIGITAL SOBRIETY

*REPORT OF THE WORKING GROUP DIRECTED BY HUGUES FERREBOEUF
FOR THE THINK TANK THE SHIFT PROJECT – MARCH 2019*

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THE SHIFT PROJECT
THE CARBON TRANSITION THINK TANK

Foreword

The Shift Project, a Paris-based think-tank on energy transition, is dedicated to tackling the decisive and delicate issues needed to make this transition a success. The exponential development of digital technology, and the way in which this development can interact with the decarbonation objectives of our societies, is one of the most important of these issues. *The Shift Project*'s members are major business players from diverse sectors.

In April 2017 *the Shift Project* asked Hugues Ferreboeuf to form a working group to collectively reflect on the possibilities of generating synergy between digital and energy transition. The aim: to maximize the positive impact of digital technology on the environment and minimize its negative impacts. In view of the numerous contradictory theses produced on the subject so far, it seemed useful to us to seek to examine all these impacts as objectively as possible, in order to draw up practical and systemic recommendations in line with decarbonation objectives.

The interim report published in March 2018 marked an important step in the process of in-depth analysis and consultation with many people and institutions involved in these issues: it provided a platform for us to enrich our thinking with the comments it will generate. The conclusions and recommendations of the working group are intended for all actors in economic, social and political life, and should help shed light on a key issue for moving towards a sustainable digital society. This report, published in March 2019, is the final version.

The interpretations, positions and recommendations contained in this report cannot be attributed to either the members of the working group or the reviewers. The content of this report is the sole responsibility of The Shift Project.

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The support of the Agence Française de Développement and the Caisse des Dépôts et Consignations, which both sponsored this project and also allowed us to interact with their teams, was invaluable.

[1] *The Shifters* are an association that supports *The Shift Project*: volunteers with very diverse profiles, experiences and skills, interested in the carbon transition of the economy, whether or not they are already active in this field.

March 2019

"LEAN ICT" --- TOWARDS DIGITAL SOBRIETY

Executive summary

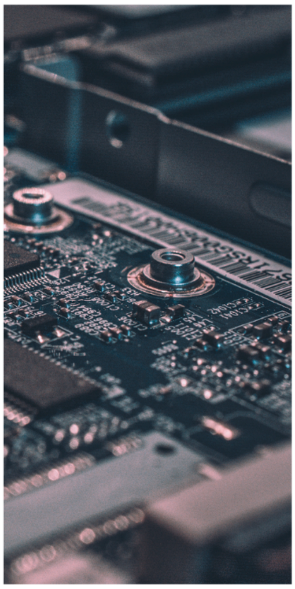
Of the report from the "Lean ICT" taskforce led by Hugues Ferreboeuf

CONTEXT

The Paris Agreement commits all countries to end fossil fuel dependency as quickly as possible. Fossil fuels represent 80% of worldwide energy consumption and are the main sources of anthropic greenhouse gas emissions. **Any increase in global energy consumption hinders the success of this historical and vital challenge: preventing climate chaos.**

Digital technologies are essential for economic and social development. **The digital transition appears to be critical** for countries and companies with digital objects and interfaces gradually becoming part of every aspect of our social life. The digital transition is also considered to be a key tool to reduce energy consumption in many sectors ("IT for Green"), to such an extent that it now hardly seems possible to address climate change without the large scale incorporation of digital technologies.

However, direct and indirect **environmental impacts (rebound effects) related to the growing use of digital are constantly underestimated**, due to devices'miniaturization and the "invisibility" of the related infrastructures. There is a real risk of a scenario in which increasingly massive investments in digital technologies would contribute to a net increase of digitalized sectors' carbon footprint– which has in practice been the case for more than a decade.



KEY TAKEAWAYS

The worldwide systemic effects of the current digital transition are for now highly uncertain, whereas they are often considered as positive *ex-ante*. With appropriate regulation, digital transition can help to reduce energy and raw materials consumption on a sectoral basis. Furthermore, the energy efficiency of digital technologies has already significantly improved. However, the major global trends of all sectors combined paint an alarming picture. Damaging environmental impacts caused by the explosion of digital technologies can and should be avoided by implementing what we call "digital sobriety".

THE DIGITAL OVERCONSUMPTION TREND IS NOT SUSTAINABLE IN REGARD TO ITS NEED FOR ENERGY AND RAW MATERIALS

The digital transition currently generates a strong increase in the direct energy footprint of ICT. This footprint includes the energy for the production and the use of equipment (servers, networks, terminals) which is increasing rapidly, by 9% per year.

- **The capture of a gradually disproportionate part of available electricity** increases the demand on electric production, which already struggles to decarbonize.
- **The share of digital technologies in global greenhouse gas emissions has increased by half since 2013,** from 2.5% to 3.7% of global emissions.The demand for raw materials such as rare and critical metals, essential for both digital and low-carbon energy technologies, is also growing.
- **The explosion of video uses** (Skype, streaming, etc.) and the increased consumption of short-lifespan digital equipment are the main drivers of this inflation.

THE DIGITAL INDUSTRY'S ENERGY INTENSITY IS INCREASING GLOBALLY

This increase, 4% per year, is in stark contrast to the trend of global GDP's energy intensity evolution, which is currently declining by 1.8% per year.

- **The direct energy consumption caused by $1 invested in digital technologies has increased by 37%** compared to 2010.
- **This evolution goes against the objective set in the Paris Agreement to decouple** both energy consumption and climate change from GDP growth.Therefore, the real trend of digital is in opposition to its presupposed function of dematerializing the economy.
- **The CO_2 emissions of digital technologies increased by about 450 million tons** since 2013 in OECD countries, while globally, overall CO_2 emissions decreased by 250 million tons of CO_2 over the same period.
- **The net contribution of digital technologies to reducing negative environmental impact is yet to be determined**, sector by sector, by being aware ofthe numerous possible rebound effects.

CURRENT DIGITAL CONSUMPTION IS HIGHLY POLARIZED

Digital consumption profiles are extremely contrasted. In 2018, an average American owns 10 digitally connected devices and consumes 140 Gigabytes of data monthly while an average Indian only owns one device and consumes 2 Gigabytes monthly.

- **The digital overconsumption is not a global phenomenon: it is caused by high income countries,** for which the major challenge is to take back control of their digital uses.
- **Expected impacts of the digital transition on growth and productivity remain invisible** in developed countries over the last 5 years. OECD's growth rate remains stable around 2% while the annual growth of digital expenditures has increased from 3% to 5%.
- **The key challenge is to plan and prioritize investments** by ensuring they efficiently serve sectoral energy efficiency priorities, as well as recognizing that developing countries will derive the greatest benefits from increasing use of digital technologies.

THE ENVIRONMENTAL IMPACT OF DIGITAL TRANSITION BECOMES MANAGEABLE IF IT IS MORE SOBER

To move from intemperance to sobriety in our relationship with digital technologies would limit digital's energy consumption increase to 1.5%. While this is in line with the global trend for all sectors combined it is not compatible with the Paris Agreement's objectives.

- **Our *"Sobriety"* scenario is possible without challenging the core principles of the digital transition.** In this scenario, the volume of data flowing through data centers and mobile networks would increase respectively by 17% and 24% per year, and both smartphones and televisions yearly productions stabilize around 2017- whereas their markets in developed countries are close to reaching saturation.
- **Our *"Sobriety"* scenario is not sufficient to reduce digital environmental footprint.** It only prevents its explosion. Its reduction will need additional efforts.

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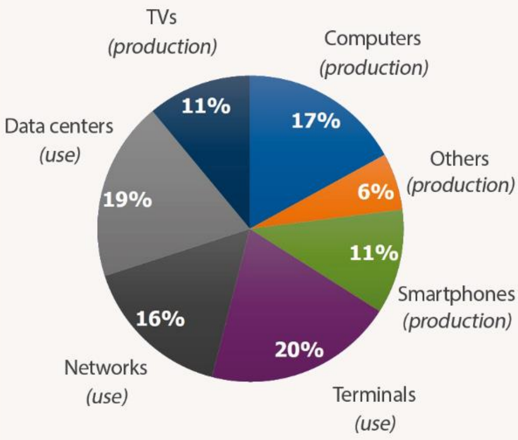
The study that gave rise to this summary was carried out with the support of Caisse des Dépôts and the Agence française de développement.

GLOBAL ANALYSIS

***The Shift Project* gathered a panel of experts to assess the environmental impact of digital technologies, in the context of digitalization**, and therefore the rapid increase of both data flows and installed base of terminals as well as the multiplication of digital uses.

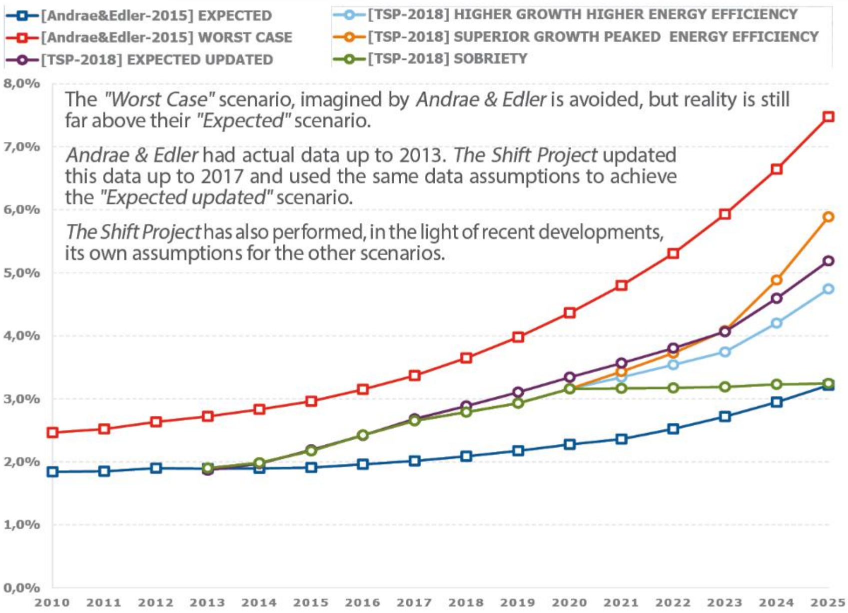
- Experts focused on the **consequences of climate change, on energy consumption** (production, utilization) and on the raw material supply (physical and geopolitical constraints, etc.).
- The definition adopted for "digital" is broad, coherent with the one retained by key sector stakeholders in their forward-looking perspectives. This definition includes **telecommunication networks** (access and transport, stationary, wifi and mobiles); **data centers**; **terminals** (stationary and portables personal computers, tablets, smartphones, traditional mobile phones, "boxes", connected audiovisual devices including televisions; **IoT sensors** (Internet of Things). This scope excludes non-communicating digital devices integrated into cars as well as numerical components of industrial production supply chain.
- Project director, Hugues Ferreboeuf, gathered **academics, professionals and sector experts**: Françoise Berthoud (CNRS, GDS EcoInfo), Philippe Bihouix (metal experts), Pierre Fabre (AFD), Daniel Kaplan (FING), Laurent Lefèvre (INRIA), Alexandre Monnin (INRIA, ESC-Clermont Origiens Media-Lab), Olivier Ridoux (IRISA, Universite de Rennes), Samuli Vaija (ACV expert), Marc Vautier (eco-conception expert), Xavier Verne (major IT projects experts) , Alain Ducass (energy and digital in Africa expert), Maxime Efoui-Hess (TSP), Zeynep Kahrman (TSP).
- The task force has met on a regular basis since April 2017 and undertook both **modeling and consolidation of studies** to assess the environmental impacts of digital technologies. The team took into account nearly 170 studies, mostly published between 2014 and 2018.
- The conclusions of the work add weight and urgency to the call to *"decrease environmental impacts of digital technologies and put its innovation potential to the service of ecological transition"* which was initiated by *Iddri*, the *FING*, *WWF France* and *Green IT.fr* in the **"White Paper Digital and Environment"** in spring 2018. It also asserts the importance of the problem outlined in September 2018 by the report of the United Nations Conference on Trade and Development, which titled *"developing countries may have much to lose in the face of digital monopolies"*.

SCENARIOS FOR 2025



Distribution of energy consumption per digital workstation for production and use in 2017.

[Source: *The Shift Project* 2018, as of Andrae & Edler 2015]



Evolution of global energy consumption of digital between 2010 and 2025, as a proportion of total world energy consumption

[Source: *The Shift Project 2018*, as of Andrae & Edler 2015]

MANAGEMENT TOOLS

***The Shift Project* elaborated several tools to help this paradigm shift.** Intended for large organizations (public administrations, banks, large service companies), these tools should be coupled with public policies pursuing the same objectives.

- **A DIGITAL ENVIRONMENTAL REPOSITORY (DER)** that gives, in an accessible way, verified accounts of the magnitude of energy and raw materials required for the production and use of common digital technologies.
- **LEVERS FOR THE MANAGEMENT** of large organizations: those levers are actions enabling them to act on both demand and consumption of digital services, without hindering their digital transition.
- **PRINCIPLES FOR PUBLIC POLICIES**, notably intended for developing countries, to help them reap the benefits expected from the digital transition.

DIGITAL SOBRIETY: HOW CAN WE DEPLOY IT?

A sober digital transition mainly consists in buying the least powerful equipment possible, in changing them the least often possible, and in reducing unnecessary energy-intensive uses. Digital sobriety is a "lean" approach, which is also a source of efficiency for organizations. Its principle expands to a societal level the consideration of objectives pursued by technical approaches such as "Green IT" and confirms their importance.

***The Shift Project* calls on companies and governments to adopt digital sobriety as a principle of action.** Lower environmental and energy footprints of the digital go through our individual and collective abilities to question the economic and social utility of both our purchasing and consumption behaviors of digital objects and services, and to adapt them in consequence.

Accelerate the awareness of the digital environmental impacts in corporations and public organizations among the general public and the research community.

Include environmental impacts as decision-making criteria when developing policies for the purchase and use of digital equipment. This concerns private as well as public organizations, in both developed and developing countries.

Enable organizations to manage their digital transition in an environmentally responsible manner, with tools and references that enable them to assess the environmental impact of the digital's component of their choices, at different levels of control. Taking advantage of the "Digital Environmental Repository" example, we call for the implementation of a public database (such as French Ademe's carbon impact database) in order to enable stakeholders to analyze their environmental impact.

Undertake carbon audits for digital projects, to include this data into the wider analysis. The supply-side pressure (GAFAM, BATX*) and the GDP growth expectations related to digitalization shall not be the only criteria for the project selections. In addition, the potential economic, environmental and social benefits are greater for developing countries, where infrastructures are yet to be developed.

Improve the consideration of digital systemic aspects in key sectors such as energy, transports, housing, and agriculture-food. Develop an expertise around this approach to accelerate its implementation.

Implement those actions to the European level and with international organizations, given the global scope and economic power of the main digital players.

**GAFAM (Google, Apple, Facebook, Amazon, Microsoft), BATX (Baidu, Alibaba, Tencent, Xiaomi)*

Contents

Foreword 2
Acknowledgements 3
Executive Summary 4
Contents 6
Index of figures and tables 8
List of abbreviations 9
Introduction: Digital technology, an opportunity or handicap for energy transition? 10
a. A tool to limit energy consumption... 10
b. ...or an irresistible societal evolution... 10
c. ...Creating uncontrollable cascades of rebound effects? 11
I. Objectives and working approach of the lean ICT project 12
a. The three project objectives 12
b. The working group's approach 12
II. Key issues and findings 14
a. Methodological remarks 14
b. Macro analysis 14
III. Digital Environmental Repository (DER) 27
a. Reference perimeter 28
b. The main calculation assumptions 28
c. The production phase: extraction and production of devices 29
d. The utilization phase: digital devices and actions 31
e. Observations and trends 34
f. The foundations of a universal digital repository 35
IV. Digital sobriety in the company: examples of action levers 36
a. Scope of recommendations 36
b. Calculation methodology 36
c. Levers no.1 & no.2: Lengthening the lifetime of professional devices 37
d. Lever no.3: Increase the BYOD share of BYOD smartphones 38
e. Lever no.4: Favoring the exchange of office documents on a shared platform 39
f. Lever no.5: Implementing operational metrics 40
V. Digital sobriety and developing countries 42
a. Digital technology in developing countries 42
b. Digital technologies and the environment 51
c. Recommendations 58
Conclusions 60
Appendices 64
a. Appendix 1: Energy consumption and digital technology 2013-2025 64
b. Appendix 2: Evolution of the number of connected terminals 65

c. Appendix 3: Evolution of data center traffic and networks 66
d. Appendix 4: Methodological note of the "Digital Environmental Repository" 68
e. Appendix 5: Methodological note of "Corporate levers" 74
f. Appendix 6: Least Developed Countries (UN-OHRLLS) 80
g. Appendix 7: Principles for digital development 82
References 83

Index of figures and tables

Figures

Figure 1: Evolution 2013-2025 of energy consumption of digital technology in TWh 16
Figure 2: Evolution 2010-2025 of energy consumption of digital technology versus world energy consumption. 17
Figure 3: Evolution 2013-2025 of the share of digital technology in GHG emissions. The share of digital technology in GHG emissions. 18
Figure 4: Emission trajectories compatible with a temperature increase limited to 2°C. [Source: The Shift Project, 2016] 19
Figure 5: Distribution of digital energy consumption per item in 2017 (P: Production) 20
Figure 6: Annual production of smartphones and world growth of stock 21
Figure 7: Evolution of deliveries of connected domestic appliances 21
Figure 8: Evolution of shares of traffic 2016-2021 23
Figure 9: The main metals of ICTs. 24
Figure 10: Architecture of a smartphone with metals used 24
Figure 11: Rate of recycling metals 25
Figure 12: Extraction of indium over time 26
Figure 13: Countries producing the largest amounts of critical raw materials 26
Figure 14: Carbon footprint of Apple products as specifications increase. 30
Figure 15: Number of connected devices (terminals) between 2013 and 2020 34
Figure 16: Annual growth of numbers of terminals installed between 2016 and 2021 34
Figure 17: World non-connected population. 43
Figure 18: Access to ICTs by development status, 2017 estimates 43
Figure 19: Internet adoption and connectivity gaps, by region (percentage of population using or connected to mobile broadband 44
Figure 20: WSIS Action lines – SDGs Matrix -at a glance- (1) 45
Figure 21: WSIS Action lines – SDGs Matrix -at a glance- (2) 46
Figure 22: Smartphone penetration in India. 47
Figure 23: Smartphone penetration in Sub-Saharan Africa. 47
Figure 24: Smartphones as a percentage of total mobile connections excluding cellular IoT 48
Figure 25: Foreign investments in digital infrastructures. 48
Figure 26: Estimated investment costs of universal connectivity. 49
Figure 27: The job market is increasingly polarized in many developing countries. 50
Figure 28: Policy framework for investment in the digital economy 52
Figure 29: Disparity of access to the Internet within African countries. 57
Figure 30: World energy intensity. 60
Figure 31: Comparative evolution of rates of growth of ICT expenses and GDP. 61

Tables

Table 1: World digital energy consumption in TWh 15
Table 2: World digital GHG emissions of inGigatonnes of CO_2eq 17
Table 3: Number of devices per capita 22
Table 4: Digital devices in a household of 4 persons in an OECD country. 22
Table 5: Metals used for low-carbon energy technologies 25
Table 6: Digital Environmental Repository (DER), Production phase 29
Table 7: Digital Environmental Repository (DER), Utilization phase – Devices 32
Table 8: Digital Environmental Repository (DER), Utilization phase – Digital actions 32
Table 9: Share of utilization in direct GHG emissions 33
Table 10: Quantification of the effect of Corporate Levers no.1 and no.2, Synthesis. 38
Table 11: Quantification of the effect of Corporate levers no.3, Synthesis. 39
Table 12: Quantification of the effect of the Companies lever no.4, Synthesis. 40
Table 13: Quantification of the effect of Corporate lever no.5, Synthesis. 41
Table 14: Evolution 2017-2023 of the energy consumption of digital technologies in India and Sub-Saharan Africa. 55
Table 15: Number of digital devices per capita by region. 56
Table 16: Evolution and share of the energy consumed by digital technology in the developing countries. 57

Table 17: Geographic distribution of digital consumption and its GHG emissions 61

List of abbreviations

IEA	International Energy Agency
BATX	Baidu, Alibaba, Tencent, Xiaomi
CAGR	Compounded annual growth rate
UNCTAD	United Nations Trade and Development Agency
CO_2eq	Designates the global warming potential of a greenhouse gas, calculated by equivalence with a quantity of CO_2 that would have the same global warming potential.
ISD	Information Systems Department
DDD	Department of Sustainable Development
GAFAM	Google, Apple, Facebook, Amazon, Microsoft
GHG	Greenhouse gas
ICT	Information and communication technologies
IoT	Internet of Things
NDC	Nationally Determined Contribution
OECD	Organization of Economic Cooperation and Development
ODD	Sustainable Development Objective
DC	Developing country
PUE	Power Usage Effectiveness
DER	Digital Environmental Repository
SDG	Sustainable Development Goals (ODD)
SSD	Solid State Disk
UN	United Nations
UNDP	United Nations Development Program

Introduction: Digital technology, an opportunity or handicap for energy transition?

In order to prevent climate chaos, the international climate agreement signed in Paris in December 2015 commits all the nations of the planet to abandoning fossil fuels as quickly as possible, as they are responsible for the greater part of anthropogenic greenhouse gas emissions. Any increase in overall energy consumption makes it more difficult to meet this vital historical challenge.

In this context, the voracious energy consumption of digital systems and its current and potential interactions with climate policies raise many questions.

Today, Digital technology is almost unanimously considered as the main lever for economic and social development:

"Growth, jobs and services are the most important benefits of investing in digital technology.[…] Digital technologies help businesses become more productive; people find jobs and expand their opportunities; and governments provide better services to all." (The World Bank, 2016)

In developed countries where the digital transformation of businesses and the public sector is accelerating, it is seen as "the" solution to return to growth:

"415 billion euros[2] *to the European economy and thus stimulate job creation, growth, competition, investment and innovation. It could expand markets, offering better services at lower prices, transform public services and create new jobs. It would encourage the creation of new businesses and enable existing businesses to grow and innovate in a market of over 500 million people."* (European Commission, 2018)

In developing countries, where investment in digital infrastructure appears just as essential as investment in electricity or transport infrastructure, its capacity for disruption appears to be an opportunity to enter the third Industrial Revolution without delay, even if there is a risk of social fracture linked to the degree of appropriation of this technology.

"A McKinsey study published in November 2013 revealed the extraordinary potential of digital technology on the continent: in 2025 Africa could see the Internet contribute $300 billion to its economy, including $75 billion from online businesses, with another $300 billion in productivity gains in many strategic sectors". (Les Echos, 2016).

a. A tool to limit energy consumption...

Digital technology also often appears as a means of reducing energy consumption in a large number of sectors ("IT for Green" or "Green by IT" concepts), by allowing more efficient use of resources: energy (smart grids, small grids), transport (connected mobility), industry (factory 4.0), services (e-commerce), buildings (smart building), agriculture (smart farming, smart water), etc.

So much so that it is increasingly considered that it would not be possible to control climate change without massive recourse to digital technology.

Moreover, the material footprint of digital technology is largely underestimated by its users, given the miniaturization of equipment and the "invisibility" of the infrastructures used. This phenomenon is reinforced by the widespread availability of services on the "Cloud", which makes the physical reality of uses all the more imperceptible and leads to underestimating the direct environmental impacts of digital technology.

b. ...or an irresistible societal evolution...

From this point of view, the Digital Transition is intimately linked to a profound psycho-social transformation whose effects are already clearly observable in generations Y and Z in whom, for example, "there is today, between the object and its carrier, an organic type of intimacy, a relationship of continuity in which the object is more directly effective in ensuring direct enjoyment than any human partner". Digital equipment (smartphones in particular) is increasingly perceived as an extension of oneself, making it all the more problematic, even painful, to become aware of these impacts.

[2] Per year, which is nearly 3 points of GDP

c. ...Creating uncontrollable cascades of rebound effects?

The indirect beneficial impacts on energy consumption are often overestimated, mainly because indirect negative impacts are not taken into account. As for the positive gains linked to progress in efficiency (in time, energy resources, etc.), they are overestimated because of the **failure to take into account the "rebound effects**[3]**", which lead to increased consumption of resources whose efficiency or ease of use has been increased.**

It seems clear that there is no example of a technology that has been introduced in the last fifty years that has allowed, on its own, a net reduction in the use of materials or energy in the processes in which it has been integrated, as Christopher L. Magee and Tessaleno C. Devezas have shown:

"The analytical framework applied to 57 different cases clearly indicates that technological progress has not translated into "automatic" dematerialization in these different cases."

"The rebound effect can (and apparently usually does) overcompensate for the dematerialization directly induced by technological progress."

The risk linked to the rebound effects is all the greater here because **the energy and digital transition processes involved are only very rarely coordinated within the same systemic approach.**

The risk of a scenario in which increasingly massive investments in digital technology would lead to a net increase in the environmental footprint of digital sectors is therefore very real.

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[3] Identified during the industrial revolution, the "rebound effect" describes how the improvement in the energy efficiency of a particular object (locomotive, computer, etc.) usually leads not to a decline, but on the contrary to an increase in overall energy consumption dedicated to the technical function which this object performs (rail transport, IT, etc.). A many studies have confirmed this state of affairs. See in particular (Santarius, Walnum, & Aall, 2016)

I. Objectives and working approach of the lean ICT project

a. The three project objectives

The definition of what Lean ICT can cover will appear when reading this report. Such a definition, in terms of practical recommendations, is the very purpose of the project. However, it can already be stated that this Lean ICT approach refers both to a concern for sobriety in the consumption of resources and to the satisfaction of targeted needs.

It is impossible to evaluate decisions without measuring their effects, or defining objectives or trajectories without being able to describe an initial state.

In order to shed light on the structuring choices that political and economic decision-makers will have to make over the next three to five years, to **coordinate the energy and digital transition processes in the same systemic approach**, *The Shift Project* has set itself three objectives.

1. Objective 1: Quantitatively clarify the impacts

Clarify the direct environmental impacts of Digital technology through a quantitative approach, both from the global point of view and in terms of usages or characteristic equipment, through **the publication of a Digital Environmental Repository (DER),** in order to have reliable benchmarks immediately mobilizable by non-specialists in collective and individual decision-making. It is indeed difficult today to find these data, since trying to do so means immersing oneself in a vast sea of academic works and technical manuals. The need for such a freely accessible reference data set was reasserted in a White Paper published in March 2018 by *IDDRI*, *Fing*, *WWF* and *GreenIT.fr* (Iddri, FING, WWF France, GreenIT.fr, 2018).

2. Objective 2: Identify trends and levers

Quantitatively highlight the impact on environmental impact of investment policies, management practices and practices within companies on the one hand, and developing countries on the other, and **simultaneously identify** levers for improvement and their economic, social and environmental consequences. We have deliberately focused only on these two examples of digital ecosystem, in order to have not only qualitative but also quantitative analyses of the effectiveness of these levers.

3. Objective 3: Propose actions

To carry out **actions to promote good practices in order to ensure the rational use of digital technology**, including in the service of more global sustainable development initiatives, among political and economic decision-makers in France, Europe and globally, in coordination with other public or private actors sharing the same objectives.

b. The working group's approach

A working group of 10 people - academics, professionals and experts in the sector - has been meeting regularly since April 2017, in view to performing modelling and study consolidation, as well as exchanges of expertise. These meetings are supplemented by interviews with stakeholders and experts on the issues concerned.

Some points are further explored by *The Shifters*, *The Shift Project*'s network of volunteer partners. We also use the advice of other Shift Project working groups as necessary.

A large bibliography was compiled with nearly 170 works, most of which were published between 2014 and 2017 (we focused on this period, given the pace of change in the sector, uses and digital technologies). Most are scientific articles or studies performed by public bodies.

We preferred articles citing primary sources of information and describing in detail the calculation methodology used by their authors.

Indeed, we quickly realized that much of the literature on the subject used figures from previous documents, very often without cross-referencing them with others, and without taking precautions regarding the limits of their validity.

These limits may come from:

- excessive age;
- the fact that the figures are the result of a model, necessarily based on simplifying assumptions which may have become obsolete;
- the size and specificities of the sample in the case of measurements.

It should also be noted that there are few overall figures (at the scale of a country for example) resulting from measurements and that the discrepancies observed from one study to another come from the modelling stage or the perimeter considered.

The insufficient presence of such figures, giving rise to misperceptions, is indeed an integral component of the object of our study.

The publication of this report in March 2019 will allow us to interact in the coming weeks with other actors that explore the interactions between digital technology and the environment in France and Europe.

II. Key issues and findings

a. Methodological remarks

Given the speed of technological change, the frontiers of digital technology are changing and we have adopted a fairly broad definition, consistent with that used today by leading players in the digital sector in their forward-looking approaches (Cisco, Gartner etc.).

The scope of the equipment (and associated uses) that we have adopted to calculate the energy and environmental footprint is therefore as follows:

- Telecommunications networks (access and transport, fixed, WIFI and mobile)
- Data centers
- Terminals: personal computers (fixed and mobile), tablets, smartphones, traditional mobile phones, boxes, connected audiovisual equipment (including connected TVs)
- IoT (Internet of Things)[4] sensors

This scope excludes non-communicating digital equipment integrated in cars and digital components in industrial production lines.

We have taken into account the production phase and the utilization phase for all these items of equipment.

We have not quantified the impacts related to the end-of-life phase due to a lack of reliable data, particularly because of the low proportion of equipment supported in treatment chains (15% worldwide, Baldé et al. 2015). This situation is worrying since this situation results not only in a loss of metals but also in increasing and largely ignored soil pollution, even if the latter is located at production sites and inadequate treatment sites, or at illegal waste dumps.

The scope of our analyses is primarily global, knowing that we have described them on the European and/or French level, when the granularity of the primary sources of information allows.

b. Macro analysis

1. Energy consumption: problematic growth

As mentioned in the introduction, there are no global figures based on measurements (even at the national level) of the energy consumption induced by digital uses. The available estimates are obtained either by projecting measurements performed on samples (for example, a set of data centers) or by using more or less sophisticated models, but rarely including descriptions of all the assumptions adopted; moreover, the scope of the studies available like that on digital technology is variable.

We have **chosen to use a model developed by Andrae and Edler** in 2015 (Andrae & Edler, 2015) for four main reasons:

- the scope adopted is similar to our definition of digital technology and this scope is worldwide;
- the article is a scientific article peer reviewed before publication;
- all the assumptions used and the calculation formulas are explained;
- the granularity of the model is sufficient to carry out sensitivity studies without its level of complexity preventing the clear identification of the dimensioning parameters.

The study by Andrae and Edler develops **scenarios for the evolution of digital energy consumption from 2010 to 2030**:

- **"best case":** energy efficiency gains (of equipment, technological platforms) are accelerating and traffic growth is slowing down;
- **"expected case**": the energy efficiency gains and traffic growth rate are in line with those of the period 2010/2013;
- **"worst case"**: energy efficiency gains are lower and traffic growth is accelerating.

[4] Internet of things (IoT) is the global infrastructure for the information society, which provides advanced services by interconnecting objects (physical or virtual) using existing or evolving interoperable information and communication technologies (Union Internationale des télécommunications, 2012).

For the first step, we wanted to update the 2017 crossing point on the basis of updated data on dimensioning parameters. Then we updated the forecasts by limiting ourselves to a horizon of 2025.

We have therefore updated traffic and installed fleet data from two reports published annually by Cisco:

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

- *Cisco – The Zettabyte era, Trends and Analysis, Whitepaper* (Cisco, 2017a) describing the qualitative and quantitative characteristics of data flows through telecommunications networks and connected terminal installations from the year preceding the report to a 5-year horizon.

For terminal production, we used the figures published quarterly by Gartner[5] and IDC (International Data Corporation)[6], the statistics website Statista[7], and updated the statistics on overall electricity consumption (all sectors) from the International Energy Agency (IEA) *Headline Energy Data 2018* database.

Finally, we have defined four scenarios for our 2025 forecast:

- **"Expected updated"**: we have maintained the same rate of energy efficiency gains as in the expected case scenario, and we have updated traffic data only on the basis of figures provided by Cisco, extending trends beyond 2021.

- **"Higher growth, higher EE"**: we have assumed that energy efficiency improves more rapidly from 2015 onwards and updated traffic data based on the historical data provided by Cisco, applying the historical growth rate which is higher than in the previous scenario to the projections by 2025.

- **"Higher growth with peaked EE"**: a variant of the previous scenario, it takes into account a slight increase in traffic growth after 2020 in comparison and a peak in energy efficiency gains in 2020, particularly in data centers. This assumption is based on concerns that energy performance will be capped once all good practices have been applied (United States Data Center Energy Usage Report, 2016, page 47).

- **"Sobriety"**: identical to the "Higher growth, higher EE" scenario until 2020, then a slowdown in traffic and production growth due to the implementation of sobriety practices. This scenario also includes a deceleration of data center energy efficiency gains after 2020 to test the robustness of the approach.

It shows that **Digital energy consumption in the world is increasing by about 9% per year** (period 2015 to 2020), a trend well above the average "expected case" scenario predicted by Andrae and Edler (4%) and just below their worst-case disaster scenario (10%). This growth rate corresponds to a twofold increase in 8 years and is expected to increase in all the scenarios that do not incorporate a voluntary change in the future.

Energy consumption in Twh	**2015**	**2020**	**2025**	**CAGR[8] 2015/2020**	**CAGR 2020/2025**
Expected - 2015	2312	2878	4350	4,5%	8,7%
Worst - 2015	3677	5976	12 352	10%	15,5%
Expected updated	2389	3834	6254	9,9%	10,2%
Higher growth higher EE	2373	3622	5716	8,9%	9,5%
Superior growth peaked EE	2373	3622	7096	8,9%	14,5%
Sobriety	2373	3622	3909	8,9%	1,6%

Table 1: World digital energy consumption in TWh
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)]

[5] https://www.gartner.com/en
[6] https://uk.idc.com/
[7] https://www.statista.com/
[8] Compounded Annual Growth Rate: Ex: A sum that goes from 100 to 121 in two years has increased (CAGR) by 10% per year.

The share of digital technology in final energy consumption (growing by 1.5% per year) will have increased by almost 70% between 2013 and 2020.

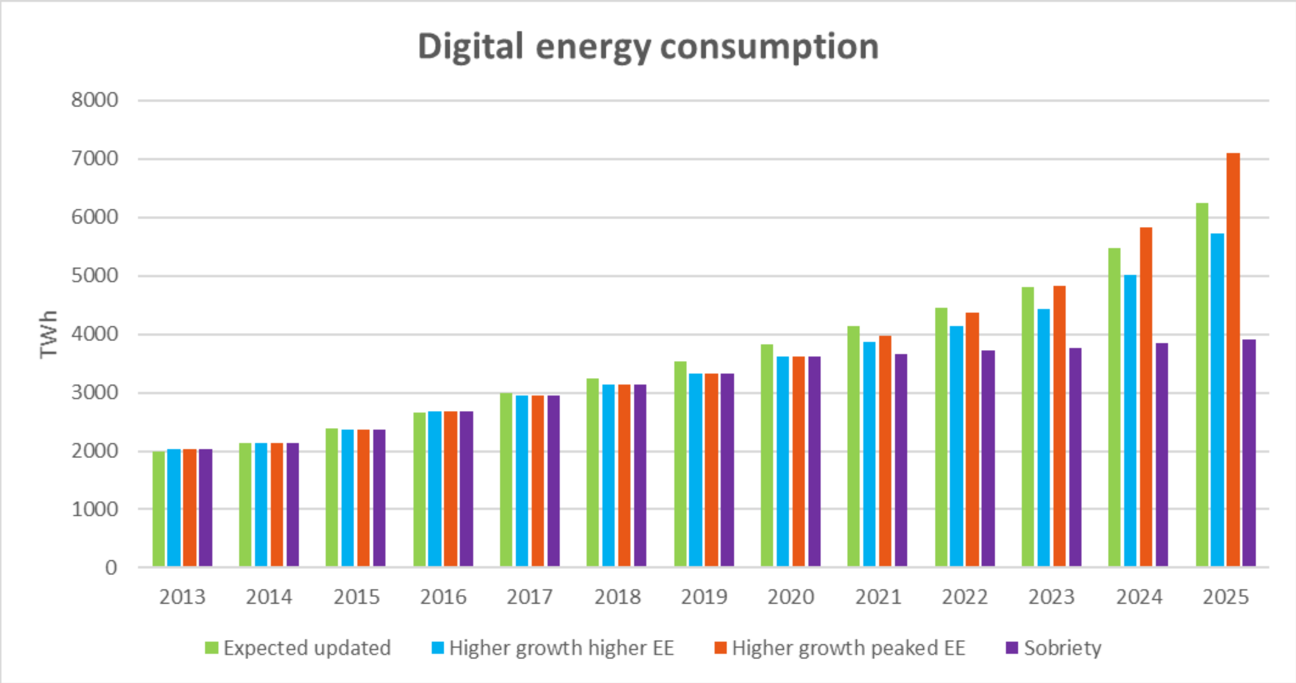


Figure 1: Evolution 2013-2025 of energy consumption of digital technology in TWh
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)]

By linking digital energy consumption to world energy consumption (with the latter growing by 1.5% per year), **this proportion (referred to here as the E-Ratio) increased from 1.9% in 2013 to 2.7% in 2017, and will reach 3.3% in 2020**.

Given the current dynamics of consumption and its inertia, it will be almost impossible to keep the E-ratio below this level by this deadline.

For the period 2020 to 2025, a comparison of the different scenarios shows the appearance of bifurcations:

- **Accelerated growth** as trends in consumption (traffic, terminals) and energy efficiency (networks and data centers) continue, leading to an E-ratio of more than 4.5% **in 2025**.
- An **explosion** if progress in energy efficiency slows down. However, this risk is real because current technologies are approaching their limits and future technologies (quantum processors for example) will not be industrialized by this deadline. Under these conditions, an E-ratio of **6% in 2025** is likely.
- A **stabilization** of energy consumption by the digital technologies if we manage to control our consumption practices (more selectivity in video use, slightly longer storage life for smartphones), despite the materialization of the risk of a lower increase in the energy efficiency of infrastructures. Under these conditions, energy consumption increases by only 1.5% per year and the E-ratio remains around **3.2% until 2025**. However, in this scenario, it is by no means a question of muzzling the digital transition: traffic growth remains very high (17% in data centers, 25% on mobile networks), likewise for purchases of supported terminals (1.5 billion smartphones sold in 2025, the same level as in 2017).

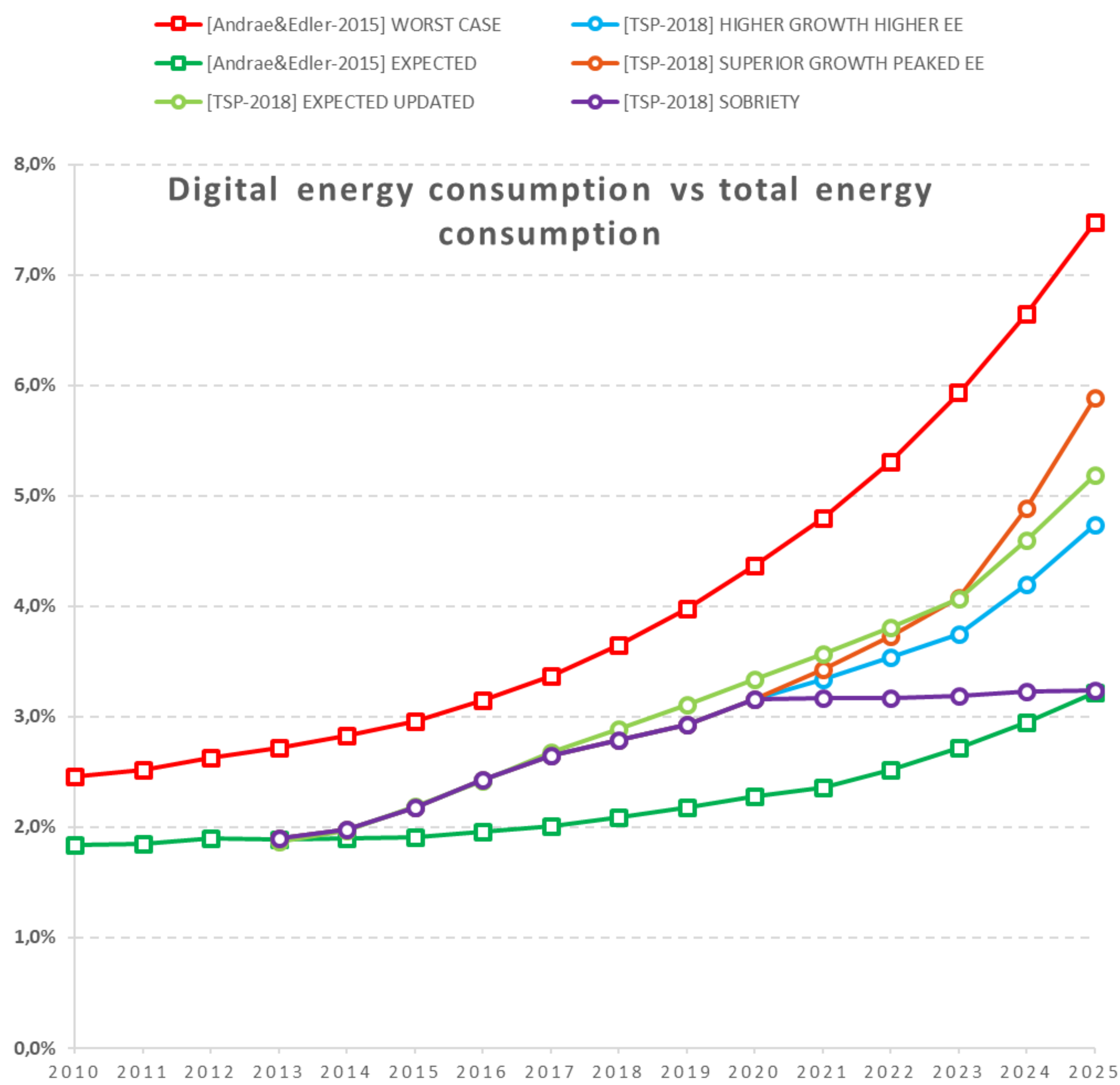


Figure 2: Evolution 2010-2025 of energy consumption of digital technology versus world energy consumption[9].
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)]

Taking into account the global electricity mix, the share of **greenhouse gas (GHG)** emissions attributable to the Digital era would therefore increase **from 2.5% in 2013 to 4% in 2020** (2.1 Gt) according to our estimate.

GHG emissions in $GtCO_2eq$	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	7.6	9.4%	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%
Higher growth with peaked EE	1.5	2.1	4.1	8%	14%
Sobriety	1.5	2.1	2.3	8%	1.2%

Table 2: World digital GHG emissions of in Gigatons of CO_2eq
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)*]*

[9] Updated by *The Shift Project* for "Expected Updated", "Higher growth higher EE", "Higher growth with peaked EE" and "Sobriety"

This figure is of the same order of magnitude as those for sectors known to consume much more carbon energy and have a much larger material footprint: the share of GHG emissions from light vehicles (cars, motorcycles, etc.) is around 8% in 2018, and that of civil air transport is around 2% in 2018. However, in comparison, in 2020, **Digital should emit as much CO2 as the whole Middle East in 2017[10].**

Even more worrying is the **growth rate of about 8% of GHG emissions due to digital technology**. Indeed, this growth must now be analyzed in the light of the objectives for reducing GHG emissions as defined at the COP 21. However, while we can expect a gradual decrease in total GHG emissions in the short term (2020, for example), the share of digital technology in these emissions will continue to increase and could **double by 2025 to reach 8%**.

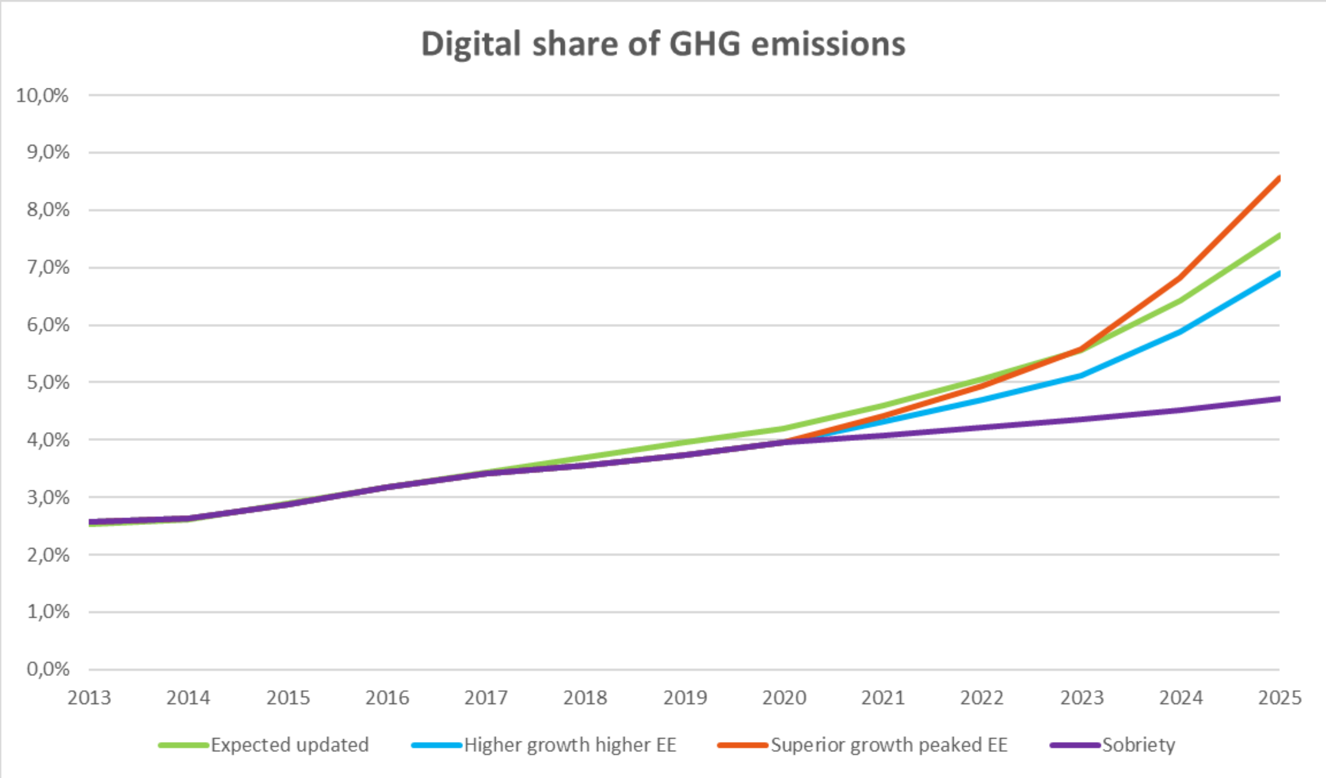


Figure 3: Evolution 2013-2025 of the share of digital technology in GHG emissions. The share of digital technology in GHG emissions.
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)

Another way to imagine the magnitude of the risk inherent in this situation is to focus on the trajectory of global GHG emission reduction needed to contain the average temperature increase to 2 degrees by 2100.

The Shift Project has shown that we would need to reduce our GHG emissions by at least 5% per year from 2018 onwards to achieve these targets (see Figure 4), which would represent 2.5 $GtCO_2eq$ at the beginning of the period, and a cumulative reduction of about 11 $GtCO_2eq$ over the first five years, i.e. until 2023.

[10] (BP, 2017) Statistical Review of World Energy 2017. From https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

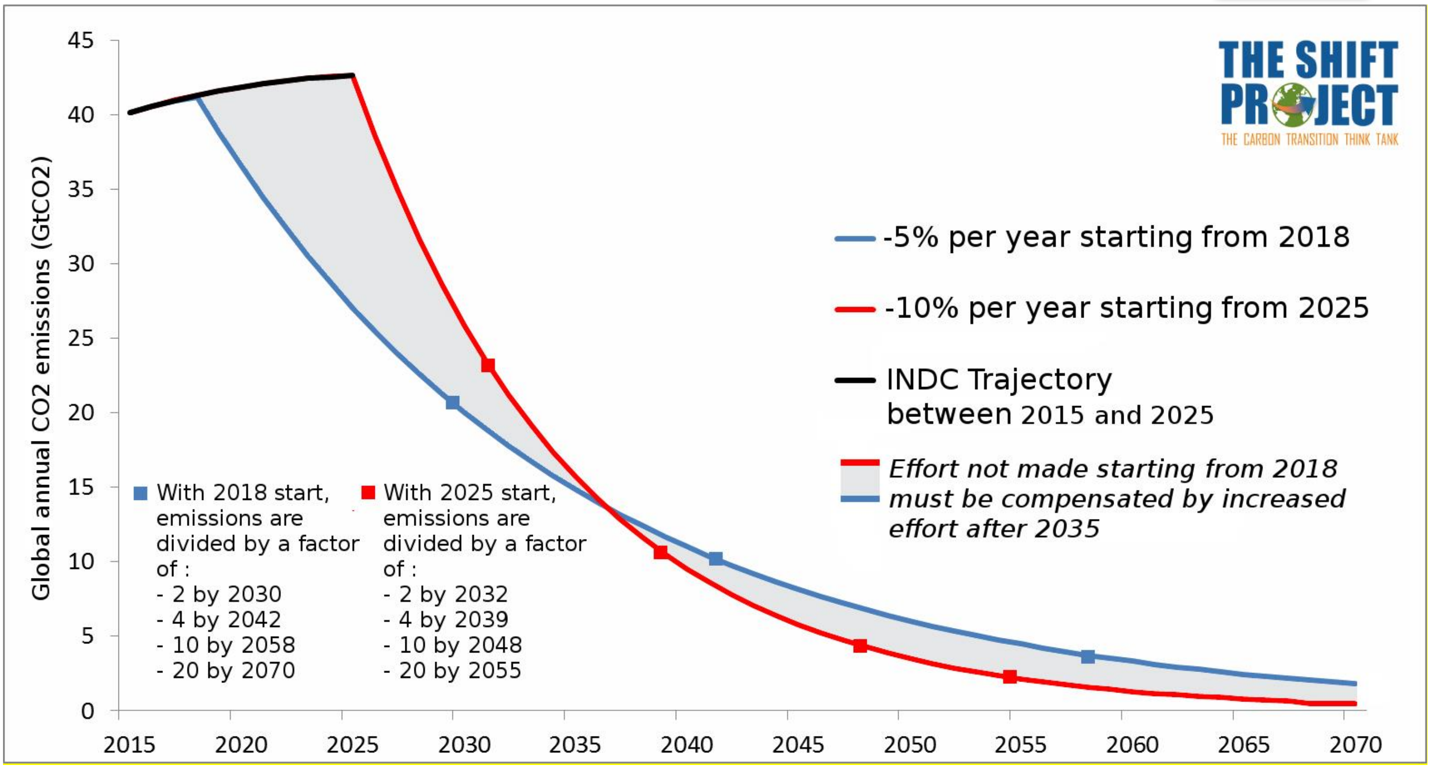


Figure 4: Emission trajectories compatible with a temperature increase limited to 2°C. [Source: The Shift Project, 2016]

At the current pace of digital GHG emissions, the total over the same period of the additional digital emissions in comparison to 2018 will be about 2.1 $GtCO_2eq$, which **would cancel about 20% of the necessary effort made to reduce them.**

The equipment production phase occupies a very significant share, around 45% in 2020, in the total energy footprint of digital technologies, as well as in the resulting GHG emissions.

NB. Our main conclusions on this point are presented in the section devoted to the presentation of the Digital Environmental Repository (DER). The orders of magnitude presented below to describe the general panorama come from the synthetic data provided by the REN.

A smartphone user (if they keep their device for two years) will thus see more than 90% of the total energy consumption induced during the life cycle of this equipment before it is even purchased[11]. This weight of the production phase in the energy impact is around 60% for a connected television but well above 80% for a laptop.

A large share of the environmental stakes of digital technologies is therefore not related to the use we make of it, but largely to the volume of material produced and its production process.

[11] We are talking here about the smartphone's own electricity consumption: if we also take into account the additional electricity consumption of the network that results from the use of the smartphone, the proportion is more akin to around 50% (See Ercan, 2013).

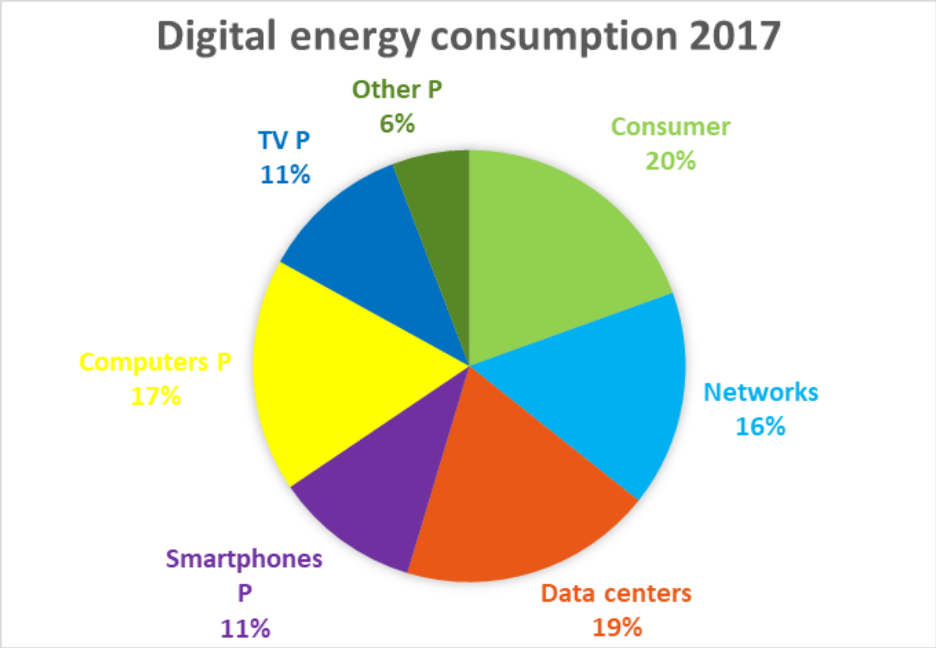


Figure 5: Distribution of digital energy consumption per item in 2017 **(P: Production)**
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)*]*

The reasons behind the strong growth in digital energy consumption are multiple but we can, on the basis of an initial analysis, identify 4 main sources:

- the smartphone phenomenon;
- the multiplication of the peripherals of daily life (or "connected living");
- the rise of the Industrial Internet of Things (IIoT);
- the explosion of data traffic.

a. The smartphone phenomenon

Not only is the base rapidly growing (4 billion in 2017, 5.5 billion in 2020, or **11% per year** (Cisco, 2017b)) but **the richness of the smartphone's features** continues to increase, which leads to greater energy consumption during its production, particularly because of the extraction of an increasingly diverse range of metals.

The energy consumption of the terminal during its use also increases[12] because of the use of more applications: a marker of this last trend is the fact that the recharging frequency of our smartphones remains more or less constant while the average battery power has increased by 50% in 5 years.

Although the latter phenomenon is a remarkable example of a rebound effect, the fact remains that the bulk of energy consumption is in the production phase: **90% versus 10% for its use**, according to synthetic data from the REN[13].

However, sales volumes (1.6 billion units in 2017, (Gartner, 2018a)) are driven not only by the **progressive equipping of developing countries** but also **by "inflationary" consumption habits in developed countries** (frequency of renewal less than 2 years), partly caused by obsolescence issues, scheduled or not: successive versions of operating systems are compatible with older generation terminals only at the cost of degraded performance and/or a significant reduction in the useful capacity of the battery.

[12] Energy consumption also increases during the recycling process because the energy used to separate metals depends on the complexity of the assemblage.
[13] The energy consumed at the end of the lifecycle is disregarded here because of the low rate of absorption in the recycling processes and the lack of corresponding data.

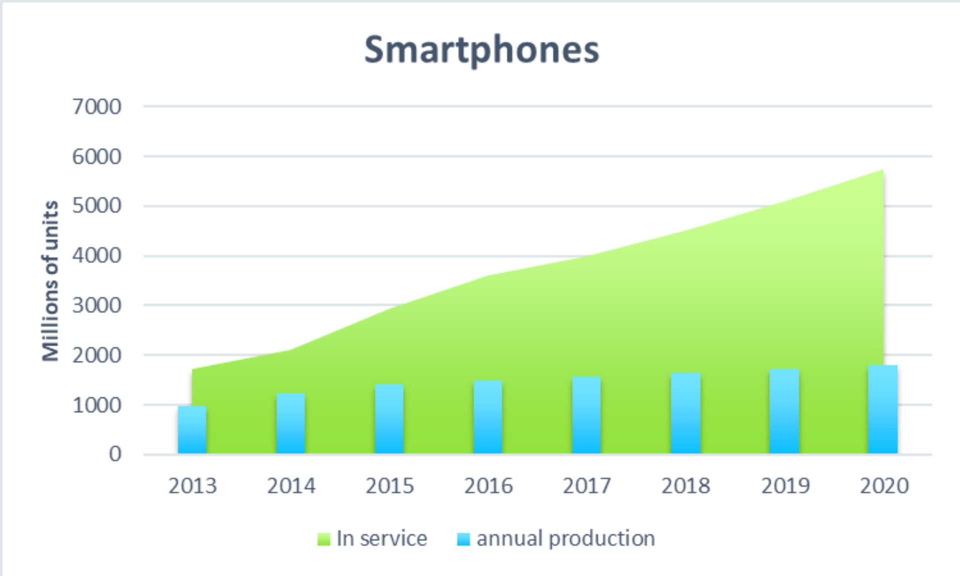


Figure 6: Annual production of smartphones and world growth of stock
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Cisco, 2014)*,* (Cisco, 2016a)*,* (Cisco, 2016b)*,* (Cisco, 2017)*,* (IDC, 2017a)*]*

b. The multiplication of peripherals of daily life (or "connected living")

New peripherals are appearing (bracelets measuring physical activity, portable Bluetooth speakers, etc.) and existing equipment in all households is becoming capable of communicating (televisions, refrigerators, coffee machines, alarm and monitoring systems, thermostats, lighting, etc.). This trend is so strong that it is leading to **growth of more than 60% per year in the production of embedded communication modules** (see Figure 7 below).

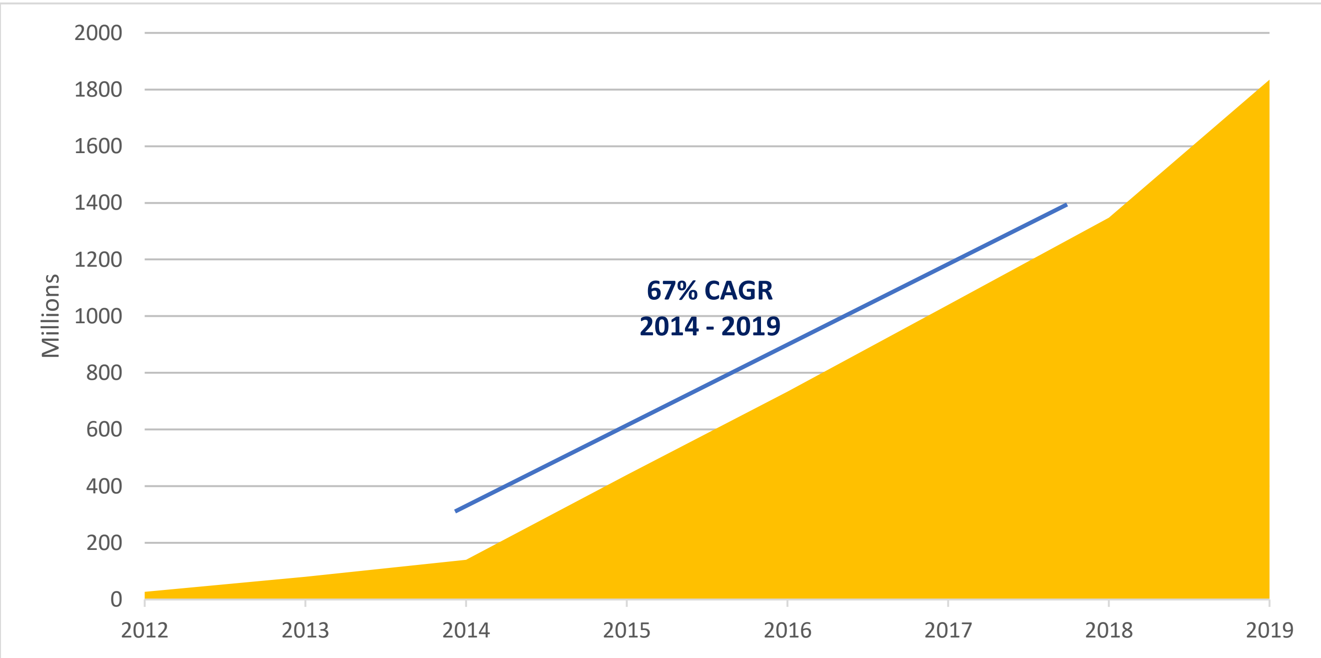


Figure 7: Evolution of deliveries of connected domestic appliances[14]
[Source: (GSMA, 2015)]

According to a GSMA study (GSMA, 2015), a household of 4 people in a developed country is expected to multiply the number of its connected digital appliances by 5 in ten years: 10 in 2012, 25 in 2017, 50 in 2022, while the global average equipment rate will increase by 50% between 2016 and 2021:

[14] The Business Insider definition of connected domestic equipment comprises all smart appliances (washing machines, tumble driers, refrigerators, etc.), safety and security systems (sensors, monitors, cameras and alarms connected to the Internet) and energy devices such as smart thermostats and smart lighting systems.

Number of connected devices per capita	2016	2021	Annual growth
Asia-Pacific	1.9	2.9	8.3%
Central and Eastern Europe	2.5	3.8	9.1%
Latin America	2.1	2.9	7.0%
Middle East and Africa	1.1	1.4	5.4%
North America	7.7	12.9	11.0%
Western Europe	5.3	8.9	10.9%
Global	2.3	3.5	8.5%

Table 3: Number of devices per capita
[Source: (Cisco, 2017b)]

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

Table 4: Digital devices in a household of 4 persons in an OECD country.
[Source: (GSMA, 2015)]

While the equipment rate is increasing in all regions of the world, **the growth in the equipment rate expected by 2021 in developed countries that are already over-equipped could be much higher than that of developing countries**: 70% in North America compared to 25% for the African continent, thus widening the existing divide, which is already considerable.

c. The rise of the Internet of Industrial Objects (IIoT)

The Industrial Internet of Things (IIoT) uses embedded technology (sensors, actuators, RFID chips, etc.) for inter-communication and identification purposes between all the links in value chains (machines, products in production, finished and in use, employees, suppliers, customers, infrastructures, etc.), which can be designated as "objects".

The connected objects can then be used to transmit information - previously known only through human manual actions - in the form of data which can then be stored and analyzed. It is **one of the technological pillars of Industry 4.0**, along with robotics and artificial intelligence.

The IIoT is leading companies to make considerable investments in digital communication technologies (around $965 billion in 2017), and they are increasing rapidly (around 21% per year) (Gartner, 2017). According to Gartner, the number of such communication interfaces will increase by 55% per year, reaching **7.5 billion in 2020** (Gartner, 2017). This growth should contribute to increasing the total number of connected devices from 8.4 billion in 2017 to 20 billion in 2020.

d. The explosion of data traffic

The growth in the **number of users** equipped with at least one connected terminal (especially in developing countries), the increase in the **ratio of the number of connected terminals per individual** (from 2.1 in 2015 to 3.3 in 2020 on average worldwide), **the increase in video traffic** coupled with the increasing share of HD and UHD quality images and the shift of usage to **consumption on demand** (streaming, VOD, cloud gaming)[15] have resulted in an explosion of traffic on networks (more than 25% per year, (Cisco, 2017a)) and in data centers (+35% per year (Cisco, 2018)). This growth is occurring at a rate that surpasses energy efficiency gains in equipment, networks and data centers. These traffic forecasts are also **regularly revised upwards**.

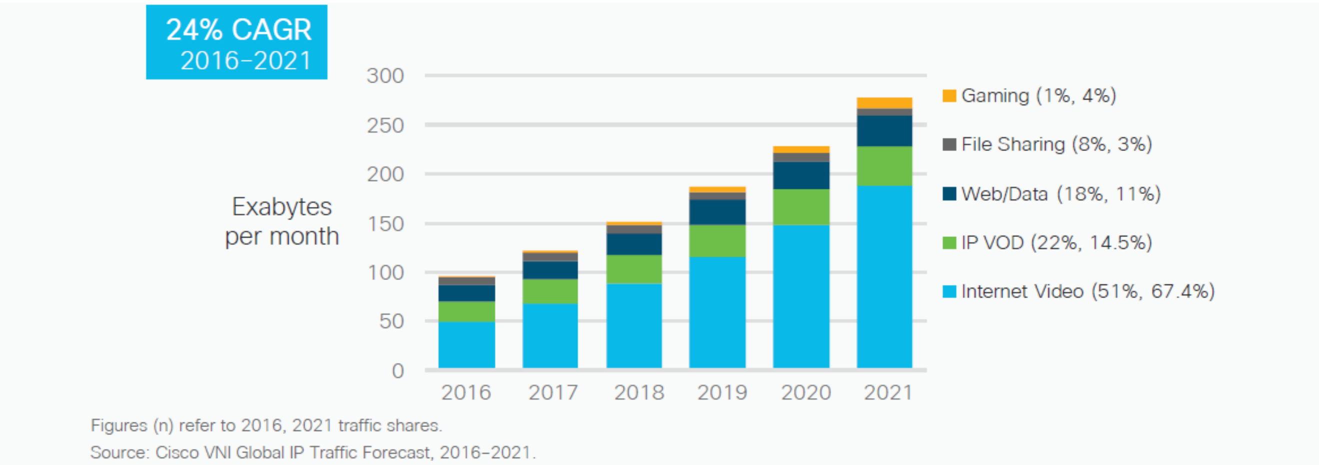


Figure 8: Evolution of shares of traffic 2016-2021
[Source: (Cisco, 2017a)]

Most of the growth in these data flows is attributable to the consumption of the services provided by the "GAFAM"[16], to such an extent that it can represent 80% of the traffic carried on the networks of certain operators. This increase in traffic is accompanied by an increase in the volume of data stored in data centers, driven by "Cloud" and "Big data" facilities, which is even more considerable: +40% per year, or 1 Zettabyte in 2020 (Cisco, 2018).

Data stored in data centers should therefore represent 20% of the volume (5 Zettabytes) of data stored in terminals, versus 14% in 2015, which will contribute to growth in traffic. Cisco estimates that 67 Zettabytes of "useful" data will be produced by the IoT and IIoT sectors in 2020, i.e. 35 times more than the storage capacity planned in data centers at that time. To ensure the full effectiveness of the "Cloud" and "Big Data" facilities currently being implemented, it will therefore be necessary:

- new architectures (edge computing[17], fog computing), deploying data processing and storage capacities as close as possible to the sensors, should be put in place so that services based on IoT and IIoT can be developed effectively. This should lead to an additional increase in active equipment and energy expenditure.
- additional storage capacity based on SSD[18] technology (including 3D NAND[19]) should be developed. This will lead to increasing the intensity of the energy used to produce this equipment linked to the manufacturing phase.

It should also be noted that **this growth is so strong that it raises the question as to the capacity available to ensure sufficient industrial production in terms of storage equipment by 2020** (Techradar, 2015).

[15] The proportion of UHD TVs will increase from 15% of the installed base in 2016 to 56% in 2021 (Cisco, 2017a).
[16] Google, Apple, Facebook, Amazon, to which we are adding more and more their Chinese counterparts Baidu, Alibaba, Tencent, Xiaomi (BATX).
[17] "Edge Computing is an open distributed computing architecture with decentralized processing power enabling mobile computing and Internet of Things (IoT) technologies. The 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/edgecomputing). Fog computing brings data processing even closer to the point of transmission, by integrating any connected object into the infrastructure.
[18] SSD or Solid State Disk or Flash memory: storage is performed in computer chips.
[19] NAND: type of Flash memory technology.

2. Rare metals: a potential vulnerability

The production of digital equipment makes it a heavy consumer of metals, some of which are rare and/or critical and whose accessible reserves (at current cost and with current technologies) are limited. Many of them also present probable production peaks in the decades to come. This situation is likely not only to weaken the development of uses but also to undermine the resilience of our digital societies.

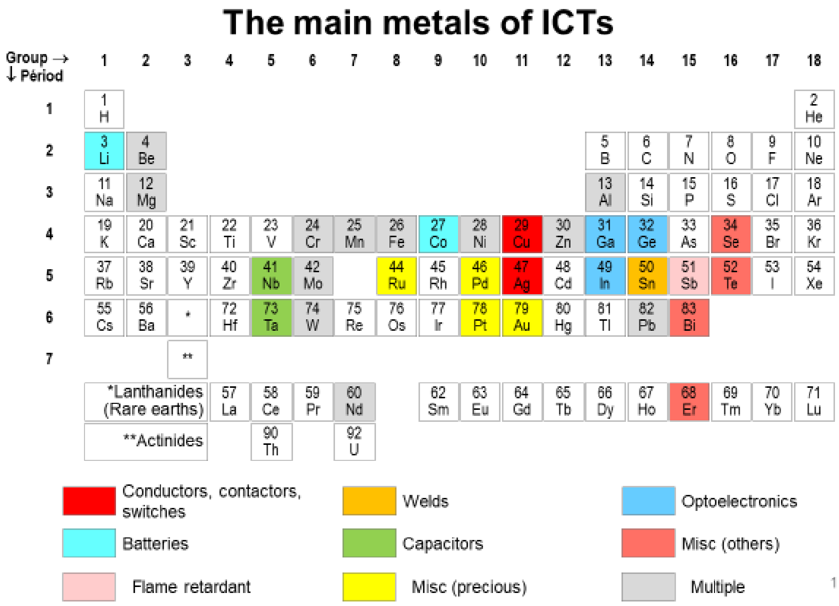


Figure 9: The main metals of ICTs.
[Source: (Bihouix P. , 2015)]

While the share of digital technologies in the overall consumption of some of these metals is relatively modest (copper, platinum, gold), this is not the case for others of which it is the main user (gallium, indium, tantalum, ruthenium, germanium). For example, at least forty metals are present in a smartphone, each in quantities ranging from a few milligrams to several tens of grams. Figure 10 provides a simplified view of the correspondence of each of the metals with a functional component, whose performance can be optimized and/or its cost reduced.

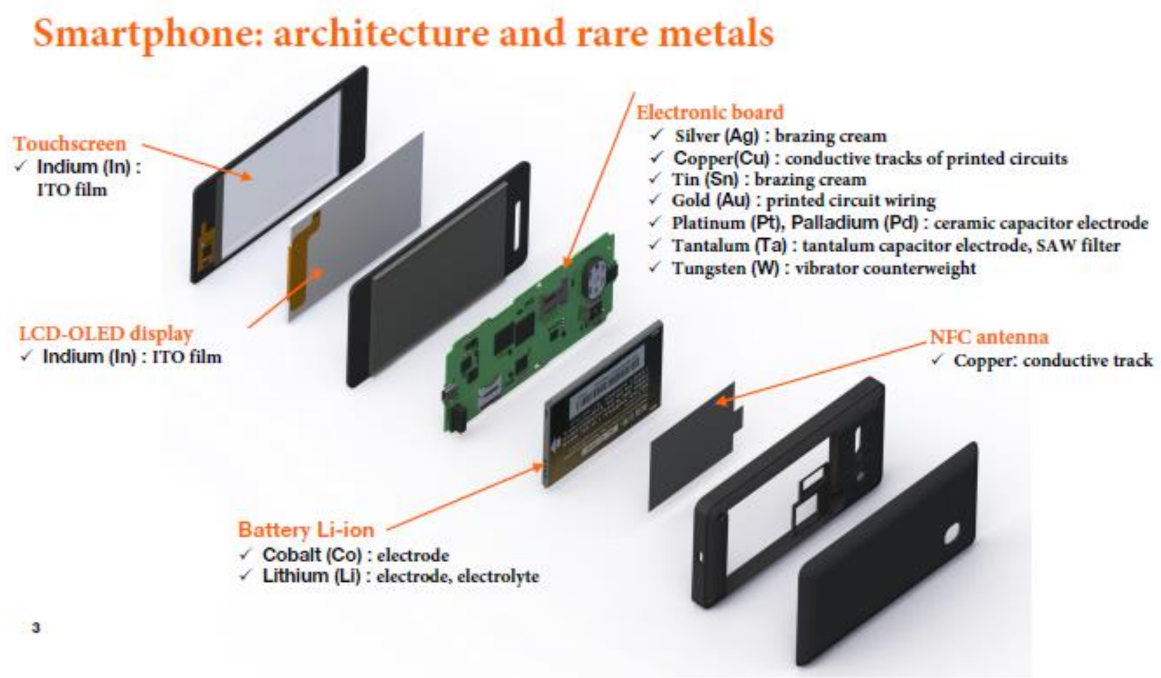


Figure 10: Architecture *of a* smartphone with metals used *(Orange Labs, 2017)*

While the increase in equipment rates and the multiplication of types of peripherals make full use of available reserves of these metals, it appears that **many of them are difficult to recycle**: for example, the recycling rate of indium, gallium, tantalum and germanium is lower than 1%.

Recycling also becomes more difficult as the number of metals in a component increases and concentrations decrease.

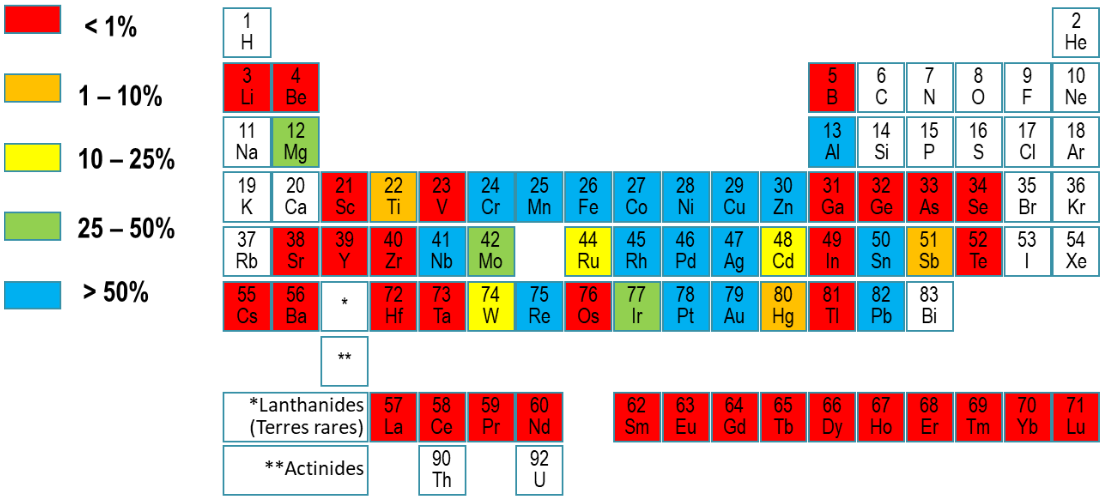


Figure 11: Rate of recycling metals
[Source: (UNEP, 2011)*]*

This situation can therefore lead to a **technological dead end** if the growth in needs does not slow down, especially since many of these metals are also used (World Bank, 2017) in large proportions for the production of equipment needed for renewable energies (wind, solar), as shown in the table below:

	Wind	Solar photovoltaic	Concentrating solar power	Carbon capture and storage	Nuclear power	Light-emitting diodes	Electric vehicles	Energy storage	Electric motors
Aluminum	X	X	X	X		X		X	X
Chromium	X			X	X	X			
Cobalt				X	X		X	X	
Copper	X	X		X	X	X	X		X
Indium		X			X	X	X		
Iron (cast)	X		X			X		X	
Iron (magnet)	X								X
Lead	X	X			X	X			
Lithium							X	X	
Manganese	X			X			X	X	
Molybdenum	X	X		X	X	X			
Neodymium (proxy for rare earths)	X						X		
Nickel	X	X		X	X	X	X	X	
Silver		X	X		X	X	X		
Steel (Engineering)	X								
Zinc		X				X			

Table 5: Metals used for low-carbon energy technologies
[Source: (World Bank, 2017)]

For example, the situation of indium points to supply difficulties as early as 2030/2035.

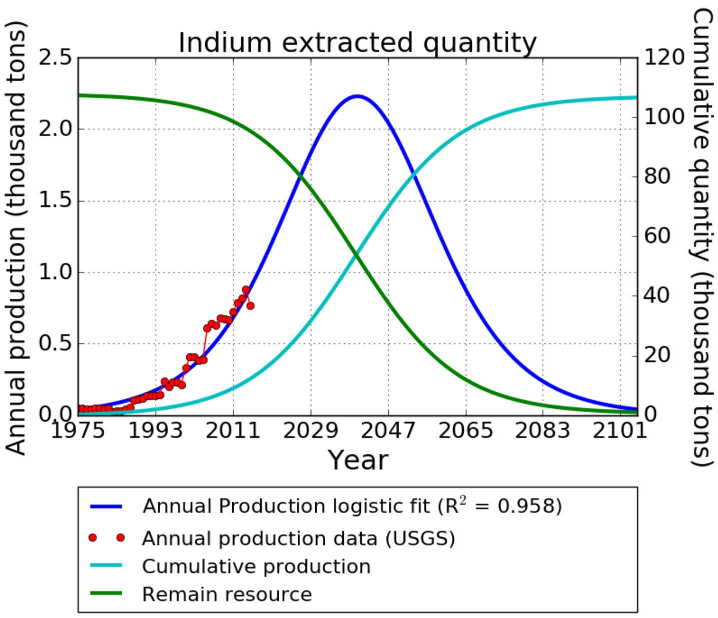


Figure 12: Extraction of indium over time
[Source: (Halloy, 2018)]

On the other hand, **these metals are a source of soil pollution during their extraction (as well as a source of GHG emissions) and at the end of the life** of the equipment when the treatment chain is not adapted (which concerns more than half by mass of electrical and electronic equipment in France, and much more in the world).

Moreover, and although this aspect is not part of the scope of analysis of our study, most of these rare metals are produced either in highly unstable countries (for example, 65% of the world's production of cobalt comes from the Democratic Republic of Congo), or almost monopolistically by a superpower (90% of the production of rare earths is under the control of China, which consumes 60% (Lepesant, 2018)). **This situation involves supply risks, or at least pressures on prices, both of which can brutally call into question industrial choices and thus the functioning of our societies, which are increasingly reliant on digital infrastructures.**

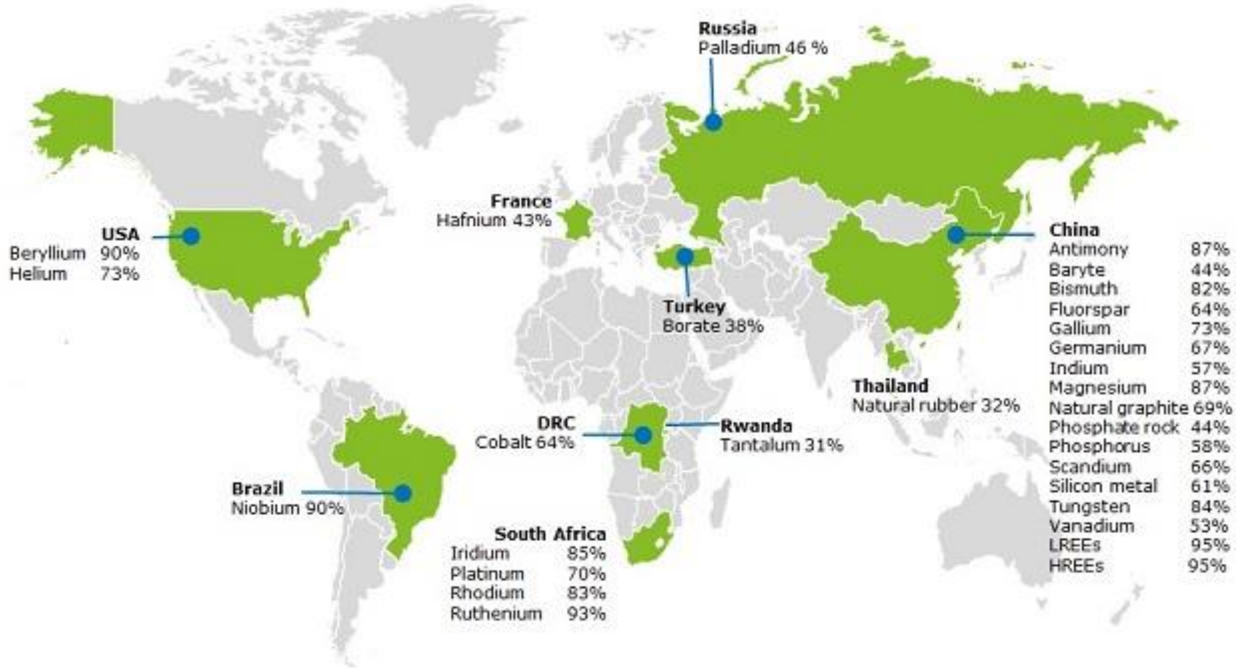


Figure 13: Countries producing the largest amounts of critical raw materials
[Source: (European Commission, 2017)]

III. Digital Environmental Repository (DER)

The aim of developing the Digital Environmental Repository (DER) is to describe, in the form of characteristic quantities and ratios, the environmental footprint of the digital ecosystem in terms of equipment and uses.

As the Digital Transition is taking an increasingly important place in both companies and society as a whole, it is **essential** that our digital **culture** is enriched by knowledge and understanding of the environmental impacts of our digital objects and actions.

In **companies and public bodies, Green IT-type approaches have often been implemented** within Information Systems Departments over the last fifteen years, and have enabled them to increase their maturity regarding this subject.

But this progress is limited by the difficulty of finding up-to-date **data** to conduct accurate environmental impact assessments, which requires delving into a vast scattered body of academic works and technical papers and/or using paid sources.

As indicated in the ADEME *report "Potential of digital contribution to the reduction of environmental impacts: state of play and challenges for foresight"* in 2016 (Deloitte Sustainable Development, 2016):

> *"(...) data on equipment is frequently old and based on a single model of device. In fact, since these are complex devices with rapid technological developments, the collection of environmental data concerning them is not easy."*

Moreover, digital technology is becoming omnipresent within organizations, whereas Green IT remains, at best, an issue solely dealt with by Information Systems Departments (IS Departments).

According to the Green IT 2017 Barometer report of the Green IT Alliance*, "(...) Green IT has still not conquered corporate governance. Less than a quarter of companies have integrated Green IT in their strategy."* (Alliance Green IT (AGIT), 2017)

According to the CIGREF study *"From Green IT to Green by IT"* published in 2017: *"IT proposes projects but they are generally only infrastructure projects, data centers, networks, operating systems, development outsourcing, infrastructure or internal governance projects."* (CIGREF, 2017).

However, these IT infrastructure projects are the consequence of decisions taken in terms of product design, organization and portfolio decisions that are not the responsibility of IT Departments, although they are increasingly taken within Digital Transition initiatives or "4.0" approaches.

Decisions have shifted to business leaders, as **digital technology is no longer seen only as a means to a strategy, but as an integral part of that strategy** and as the catalyst for transformation to adapt to a new environment.

Purely technological choices may even be made outside the IT department (what we call "shadow IT"), which is obviously not healthy in the long term, either to guarantee the sustainability of achievements or the perspective of minimizing the environmental impact of digital technology.

It is therefore necessary to have technically verified data accessible to non-specialists (of neither digital technology nor energy transition), in order to ensure both appropriate awareness of the stakes involved and the integration of the environmental impacts of digital technology in the definition of strategies, the choice of organizational structures and innovation methods.

Our Digital Environmental Repository is thus an embryo of the database that must be established if we want to inform on the decisions that can lead to a resource-resilient digital world. Its objective is to present orders of magnitude considered fundamental to make concrete the environmental impact of digital technologies. It obviously requires updating by and criticism from experts in the sector: the aim is to preserve its relevance and make it the starting point for a major project that would lead to a standardized and universal database on the net environmental impact of digital technology.

This new situation, which this Repository aims to help establish, will also strengthen the legitimacy of Chief Information Officers and Sustainable Development Directors to advise general management on the environmental management of digital transition.

a. Reference perimeter

The scope and calculation assumptions are summarized below. Details of these elements are available in the "Methodological Note of the Digital Environmental Repository" (Annex 4, page 67).

The **environmental footprint** of the digital ecosystem is characterized through the quantification of:

- Energy or electricity consumption (depending on the relevance of one or the other to the case in question);
- Greenhouse Gas (GHG) emissions;
- Consumption of critical metallic raw materials;
- The volume of ore moved for the extraction of raw materials

The elements chosen to represent the **digital ecosystem** are of two types

- Equipment (or groups of equipment);
- Digital actions" (typical uses of equipment).

The items of digital **equipment** selected in the DER are the following:

- Smartphone;
- laptop computer;
- data center;
- connected TV;
- Internet access routers ("boxes").

Digital **actions** are activities carried out via digital equipment and involve the use of networks. The actions included in REN are as the following:

- Send an email;
- Watch a video online.

Unlike terminals, for which the objective is to eventually constitute a real quantitative reference framework, the quantification of digital actions simply aims to give examples of the energy and material content of certain so-called "virtual actions".

b. The main calculation assumptions

1. Assumptions for smartphones

The impacts presented are given for an average smartphone, corresponding to an average activity performed on several brands (main manufacturers in terms of market share) and recent mid-range models. The use profile is calibrated on the basis of statistical studies on current uses worldwide according to age classes.

2. Assumptions for laptops

The impacts presented are given for an average laptop computer, corresponding to an average activity performed on several brands (main manufacturers in terms of market share) and recent mid-range models. The use profile is professional, as per professional use corresponding to the studies carried out under the American government "Energy Star" label.

3. Assumptions for data centers

The impacts presented are given for an average data center, arbitrarily characterized by its surface area and the total power capacity of its installations (in MW):

- Average data center area: 1000 m²;
- Average data center power: 1 MW;
- PUE (Power Usage Effectiveness): 2.

Emissions associated with the production phase are given for a single server in the data center.

4. Assumptions for connected televisions

The impacts shown are given for a connected TV with LED display, corresponding to the mid-range models (50 to 60 inch displays) of the main manufacturers in terms of market share. The use pattern is calibrated based on studies conducted under the American government "Energy Star" label and scientific articles.

5. Assumptions for Internet access routers

The impacts shown are given for an average router whose consumption is calculated on the basis of data from the work of the working group (within EcoInfo as well as in a company in the sector), crossed with various secondary sources of comparative studies[20].

The consumption of the Residential router is calculated for its network uses related to the IP router. Uses related to "Box TV" features are not included in this calculation[21].

6. Examples of characterization of digital actions

The action "Send an e-mail" is characterized as follows:

- Time of use of the associated terminal: 5 minutes;
- Size of data transmitted (including attachment): 1 MB.

The "Watch a video online" action is characterized as follows:

- Operating time of the associated terminal: 10 minutes;
- Transmitted data size (1080p quality video): 170 MB.

c. The production phase: extraction and production of devices

1. Energy consumption

The analysis of the production phase of devices shows very large amounts of energy used, all the higher as the level of miniaturization increases:

DER - Digital Environmental Repository *Production Phase*					
Impacts		Hardwares			
		Laptop	Smartphone	Server (Data centre)	Connected TV
	Primary Energy (MJ)	6 640	717	/	/
	GHG (kgCO_2e)	514	61	588	441
Metals	Gallium [Ga] (mg)	8	0,5	/	200
Metals	Indium [In] (mg)	20	7	/	12 000
Metals	Tantalum [Ta] (mg)	500	50	/	/
Metals	Copper [Cu] (mg)	170 000	20 000	/	885 000
Metals	Cobalt [Co] (mg)	12 000	6 000	/	/
Metals	Palladium [Pd] (mg)	1	5	/	/
	Ore Exctracted Volume (L)	7	2	/	200

Table 6: Digital Environmental Repository (DER), Production phase
[Source: "[Lean ICT Materials] DER", tab "DER Prod Phase". Produced by The Shift Project]

Thus, producing a smartphone weighing 140 grams (approximately 0.3086 lb) demands about 700 MJ of primary energy whereas, according to ADEME, about 85 GJ to produce a gasoline powered car weighing 1,400 kg (approximately 3,086 lb) (ADEME, 2013). Therefore, it is necessary to consume 80 times more energy to produce "a gram of smartphone" than to produce **"**a gram of car**".** It is noteworthy that **miniaturization also increases energy consumption during recycling, since the energy needed to separate the metals increases as a function of the complexity of the assembly**.

[20] Detailed in "[Lean ICT Materials] Residential Router Electricity Consumption". Produced by *The Shift Project*.
[21] Detailed in " Appendix 4: Methodological note of the "Digital Environmental Repository"

2. Greenhouse Gas emissions (GHS)

Regarding GHG production, it is useful to know several ratios and comparisons to be aware of the impacts:

- producing a smartphone generates 400 times more emissions than its utilization in France;
- by considering that a person uses a smartphone from the age of 10 to the age of 80 in France, and that it is replaced every two years, the result is the generation of about two tons of GHG, i.e. the equivalent of 200,000 km travelled by train, or the daily commuting of an inhabitant of the outer Paris region for the whole of their working life.

In addition, the trend in recent years gives rise for concern, since **the carbon intensity of smartphones has increased every time that a new generation is launched**, as shown by the following graph:

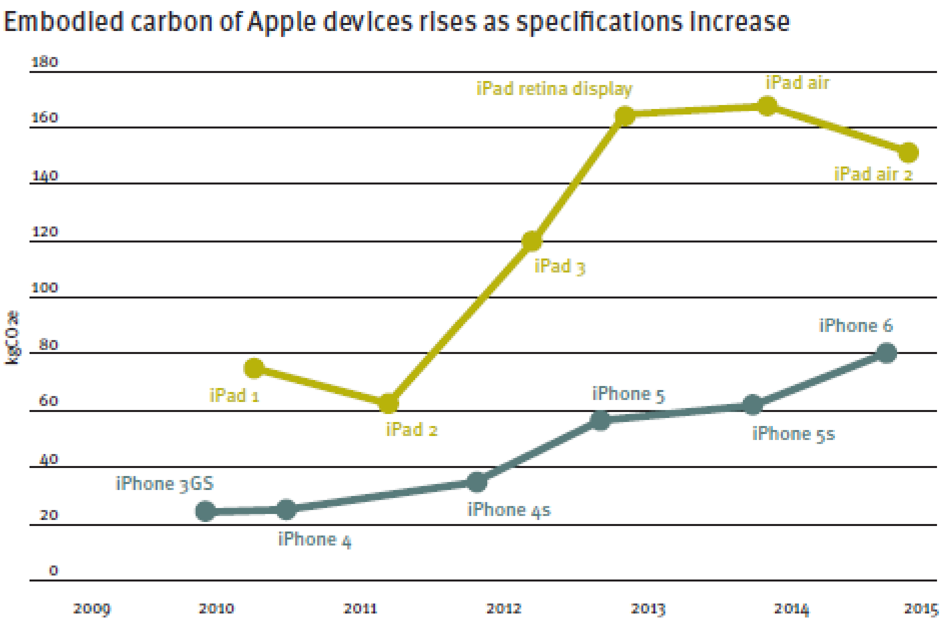


Figure 14: Carbon footprint of Apple products as specifications increase.
[Source: (Benton, Hazell, & Coats, 2015)*]*

This trend is confirmed by the most recent models: the carbon footprint of the Iphone X[22] is 93 kgCO_2eq whereas that of the Apple Watch[23] is 38 kgCO_2eq, given that this must be added to that of an Iphone (Apple, 2018).

3. Metal content

The metal content of devices is an indicator of the impact of digital technologies on natural mineral resources. **Indeed, digital transition requires the development and production of devices whose electronics are made up of mineral elements that are deemed to be "in competition" with other technologies**: transition inertia such as that with energy transition implies the development of new technologies requiring specific raw materials, especially mineral ones (alloys for the wind power industry, semiconductors for solar power technologies, new types of battery, etc.). Since we have to cope with finite quantities of natural resources, ensuring the durability of different transitions requires examining their competition for the same resource. The problem of the pressure exerted by digital technologies on natural resources is therefore not limited to energy, especially if we want to consider realistic trajectories that allow optimizing the net environmental effect of digital technology in view of the different dynamics of transition and innovation in play.

[22] Iphone X 256GB
[23] Apple Watch Series 3 (GPS + Cellular) 42mm Stainless Steel Case with Sport Band.

The metal we have chosen to quantify in our Repository were selected according to two main criteria: their criticality[24], evaluated on the basis of works performed by the European Commission (Oakdene Hollins Research & Consulting, Fraunhofer ISI, 2013), and their utilization in digital technologies, evaluated on the basis of previous works of the members of the working group (Bihouix P. , 2015) and scientific publications (Institut Mines-Télécom, 2016).

The list of metals selected is the following:

- Gallium
- Indium
- Tantalum
- Copper
- Cobalt
- Palladium

The aim of this list is not to quantify the metal content of devices completely and exhaustively, but to highlight orders of magnitudes that are pertinent in the light of current and future stakes regarding the mineral resources required for digital technologies.

It should be noted that data on the metal contents of devices are complicated to obtain and synthesize since they demand a very thorough breakdown of the physical structure of these devices and recourse to sources of highly specialized information (Institut Mines-Télécom, 2016).

At the global scale, **the total annual fabrication of smartphones uses 9,000 tons of cobalt, i.e. about 10%** of the total production of this metal. **The annual fabrication of connected televisions requires about 330 tons of indium, i.e. 50%** of world production of this metal.

4. Volume of ore moved

The volume of ore moved corresponds to the quantity of minerals required for the production of the metals contained in the devices in question. This indicator was chosen to represent partially though concretely the impact that the extraction process can have on a given ecosystem.

It permits highlighting the importance of the transformations required in the field – and thus on the ecosystems occupied – to ensure the extraction of raw materials.

The data presented here take into account only a limited number of metals contained in digital devices and thus do not pretend to be quantitatively exact. Nonetheless, they allow representing the quantity of material involved in the production of a terminal, despite the miniaturization of its components: a smartphone, having an average volume of 50 cm^3, requires the movement of about 2L of ore, solely for the extraction of the metals considered here (i.e. only gallium, indium, tantalum, copper, cobalt and palladium[25]). This is without taking into account metals such as aluminum, which makes up a large part of the weight of the finished product. This means that **for the content of only the partial content in raw materials calculated here, it is already necessary to disturb 40 times more volume of an ecosystem than the volume of the device**.

This provides understanding of the importance of characterizing the environmental impacts caused throughout the lifecycle of the product rather than only partially. It is clear that it would be misleading to limit the material dimension of devices solely to the reality perceived by the user, that of a highly compact finished product.

d. The utilization phase: digital devices and actions

1. Energy consumption of devices

The analysis of the device utilization phase first shows that energy consumption is **much lower than that of the production phase for peripheral equipment**.

[24] For an economic actor or an economy, the criticality of a mineral substance can be assessed according to two criteria: the risks of supply and economic impact. www.mineralinfo.fr
[25] cf. previous part "Metal content"

DER - Digital Environmental Repository *Run Phase*													
Impacts		Hardwares											
		Laptop			Smartphone			Data Centre	Connected TV			Residential Router
		Min	Mean	Max	Min	Mean	Max		Min	Mean	Max	
	Electricity usage (kWh / year)	13	56	100	4	6	8	6 000 000	99	157	215	100
GHG	GHG - EU ($kgCO_2e$ / year)	4	15	28	1	2	2	2 000 000	27	43	59	28
GHG	GHG - USA ($kgCO_2e$ / year)	7	28	49	2	3	4	3 000 000	49	78	106	49
GHG	GHG - China ($kgCO_2e$ / year)	9	38	68	3	4	5	4 000 000	67	107	146	68
GHG	GHG - France ($kgCO_2e$ / year)	0,5	2	3	0,1	0,2	0,3	200 000	3	5	7	3

Table 7: Digital Environmental Repository (DER), Utilization phase – Devices
[Source: "[Lean ICT Materials] REN", tab "DER Run Phase". Produced by The Shift Project]

Indeed, if we take into account periods of conservation of 2, 4 and 5 years for smartphones, laptop computers and connected televisions respectively, the energy directly consumed due to utilization represents, proportionally to the energy consumed directly throughout the entire lifecycle of the peripheral device, **6% for a smartphone, 11% for a laptop computer and 33% for a television**.

Naturally, this proportion changes if we include the energy consumed indirectly by using the peripheral device, linked to the traffic it generates in the network and to the operations it triggers in data centers. Regarding smartphones, it is in the region of 50% (Ercan, 2013).

Put otherwise, **the real energy consumption during the lifecycle of a smartphone is 33 times greater than its annual electricity consumption**, which is the only consumption that the user can possibly measure today.

2. Energy consumption of digital actions

Table 8: Digital Environmental Repository (DER), Utilization phase – Digital actions
[Source: "[Lean ICT Materials] REN", tab "DER Run Phase". Produced by The Shift Project]

Quantifying the environmental impact of digital actions has an illustrative purpose: the aim is not to pretend to model the uses of an average digital device user, but rather to put forward pertinent and verified magnitudes that give a physical quantification to acts perceived as **"**virtual**".** The two actions are chosen because they are representative of digital uses, although they obviously represent only a partial representation.

Their quantification was performed using the energy impact of a byte of data[26]: the impact calculated takes into account the consumption of the terminal used and the contribution of the network and data centers involved in transferring the information. In the light of the very considerable uncertainties inherent to this type of calculation (uncertainties contained in the original data, calculation hypothesis, a large number of situations in real contexts, etc.), the results are given in magnitudes.

These magnitudes permit obtaining several initial interesting ratios.

- Watching a video online on the Cloud for ten minutes, for example, results in the electricity consumption equivalent to the consumption of a smartphone over ten days. In other words, **the energetic impact of watching a video is about 1,500 times greater than the simple electricity consumption of a smartphone itself.** The difference that can be observed between these two types of consumption allows understanding **the importance of the impact of the network on the digital footprint**: **"**virtual**"** actions in fact use global scale infrastructures composing the Cloud, and whose operation requires a large amount of energy and thus natural resources.
- It is necessary to spend 5h writing and sending emails without stopping (i.e. 100 short emails and an attached document of 1 Megabytes) to generate an electricity consumption analogous to that generated by watching a 10-minute video film.
- Spending 10 minutes watching a **high definition video by streaming** on a smartphone is equivalent to using a **2,000W electric oven at full power for 5 minutes**.

These examples clearly show the crucial impact of watching videos on the energy footprint of digital technologies since they are at the origin of more than 80% of growth in Internet traffic (Cisco, 2017a).

3. Greenhouse Gas (GHG) Emissions

GHG emissions are obviously highly dependent on the geographical distribution of the equipment installed, due to the diversity of electric mixes according to country and their carbon intensities: 35 gCO_2eq/kWh in France versus 681 gCO_2eq/kWh in China, 493 gCO_2eq/kWh in the United States, 425 gCO_2eq/kWh in Germany and 276 gCO_2eq/kWh in Europe (International Energy Agency (IEA), 2018).

If we proceed to analyze the amount of GHGs emissions directly due to the use of peripheral devices in comparison to direct GHG emissions throughout their lifecycle with the same hypotheses of lifetime, we obtain results that confirm those obtained for energy consumption but contrasted however as a function of the regions of use:

Share of utilization in GHG emissions	France	Europe	US	China
Smartphone	0.3%	2.6%	4.5%	6.2%
Laptop	0.4%	2.9%	5.1%	6.9%
Connected TV	1.1%	8.9%	15.0%	19.5%

Table 9: Share of utilization in direct GHG emissions
[Source: "[Lean ICT Materials] REN". Produced by The Shift Project]

[26] Described in "[Lean ICT Materials] 1byte Model". Produced by *The Shift Project*.

e. Observations and trends

1. Strong growth in the number of terminals

a. Terminals: strong but contrasted growth

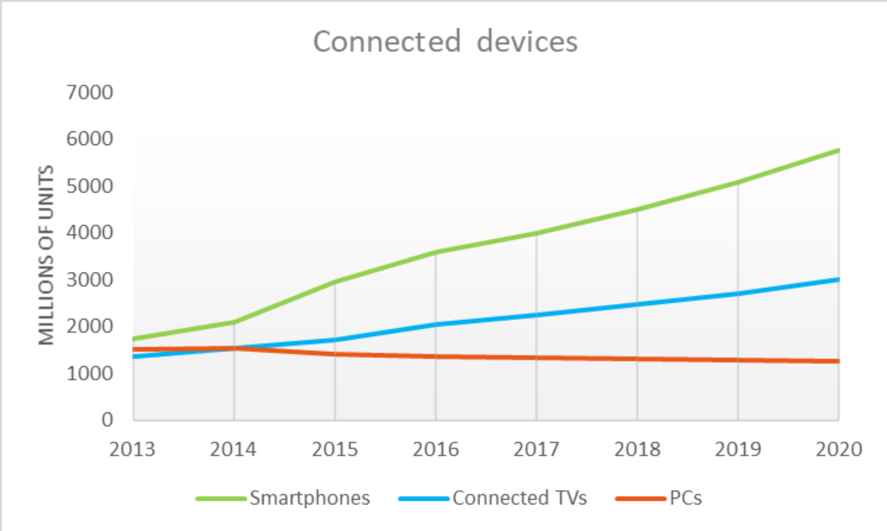


Figure 15: Number of connected devices (terminals) between 2013 and 2020
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Cisco, 2017b)*]*

The growth of uses is driven by digital nomadism and video, resulting in contrasted evolutions of the numbers of different terminals:

- the number of **smartphones** will rise from 1.7 billion in 2013 to 5.8 billion in 2020, **with growth of 11% a year**;
- there is also strong growth in the number of **connected televisions**, rising from 1.3 billion in 2013 to 3 billion in 2020, with **growth of 9% a year**; moreover, the change to the UHD standard (Ultra High Definition or 4K), associated with the increase in screen size, will lead to higher energy consumption;
- the **increase in the number of laptop computers** will not completely offset the fall in the number of desktop computers and will result in a **decrease of 2%** per year in the number installed.

b. Terminals: higher growth in regions of high carbon intensity

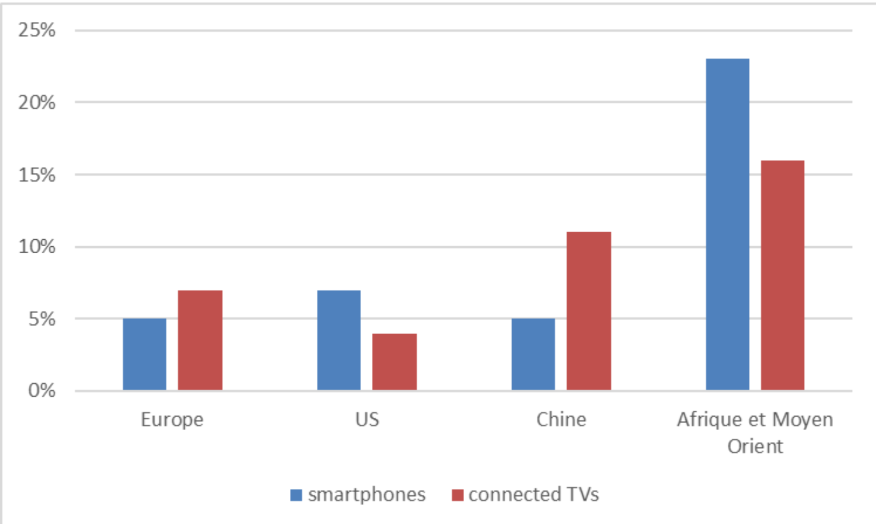


Figure 16: Annual growth of numbers of terminals installed between 2016 and 2021
[Source: (Cisco, 2018b)*]*

The faster growth of the number of connected digital terminals in regions of high carbon intensity will increase GHG emissions.

2. Data centers: factors in competition

In the Digital Environmental Repository, the impacts of data centers are calculated for an **"**average**"** site characterized by a surface area in m² and the total power capacity of its installations in MW (1,000 m^2, 1 MW, PUE of 2). Given the many variables affecting energy efficiency, the case presented here must be considered as an illustration, since the results associated do not represent an average of all data centers.

By way of comparison, the annual consumption of an equivalent installation according to EDF is that of a French town of 10,000 inhabitants (Iddri, Fing, WWF France, GreenIT.fr, 2018).

From the prospective standpoint, **it is difficult to forecast the evolution of energy consumption of data centers**: they result from a combination of numerous competing trends and effects.

Among those tending to decrease the electricity consumption of centers, there are the following:

- The improvement of the PUE of each data center;
- The improvement of the energy efficiency of the servers;
- The improvement of the rate of use of the servers;
- The improvement of the linearity of server consumption as a function of load;
- The concentration of servers in **"**hyperscale data centers**".**

The following in particular are some of the trends driving the increase in the consumption of centers:

- The growth in data traffic;
- The growth in the volumes of data to be stored;
- The increase in the volume of operations;
- The creation of data centers in regions where the technological environment is more problematic;
- The decentralization of computer power to the **"**edge**"**, in particular linked to IIoT.

Despite the existence of these two contradictory trends, **even the most optimistic studies express concerns regarding the capacity of technological progress to counter the growth in volumes by 2020.** For example, this report from the American Department of Energy and the University of California on the energy consumption of data centers in 2016 in the United States, states:

> ***"*** *The key levers for optimizing the energy efficiency [of data centers] identified in this report, better PUE, better rate of use of servers and more linear consumption all have theoretical and practical limits and the amount of progress already achieved suggests that these limits will be reached in the relatively near future.* ***"*** (Shehabi, A. et al., 2016)

f. The foundations of a universal digital repository

The Digital Environmental Repository has been designed to **contribute to responding to one of the main barriers to the efficient management of energy in digital transition: difficult access to verified and transparent data.**

The absence of an entity that centralizes studies and only partial standardization of methodologies makes any effort of synthesis highly complex: the data depend on the framework in which the studies are performed and specific hypotheses, and they all too frequently lack transparency, thus they quickly become difficult to compare with each other.

The DER is a preliminary database that is built, verified and updated by specialists and experts in the field, but which can easily be used by other actors and decision-making circles in the digital world. Since digital technology has become a crucial component in the strategies of companies, organizations and institutions, it is necessary to **build a quantified base that is as universal as possible to allow discussions between digital specialists, actors working on environmental issues and strategic decision-makers without specialized knowledge on these subjects.**

If we want to be in a position to make digital technology an asset for environmental transition, it is vital to evaluate the effect of digital technology on the environment in a granular manner and have available the information that makes possible the application of the principle of digital sobriety in operational decisions. The first milestone of such an approach must be the construction of a genuine base of reliable data, fueled and maintained both regularly and objectively. Our Digital Environmental Repository can be the embryo of this database.

Here, we agree with one of the proposals (proposal 4.1) of the White Paper **"**Digital Technology and the Environment**"** (Iddri, Fing, WWF France, GreenIT.fr, 2018) to **"**build a public database to allow actors in digital technology to analyze their environmental impacts**".**

IV. Digital sobriety in the company: examples of action levers

The tertiarization of the economy combined with digital transition results, in particular, **in an increase of digital activities in the carbon footprint of companies[27]**. This can far exceed 30% in service sectors and therefore represents an issue now becoming visible for corporate managements.

Another impact of digital transition and the spread of service models in the Cloud, giving simplified access to applications, platforms and infrastructures, is that they **make it more difficult for CIOs to exercise the governance entrusted to them**, since an increasing share of digital expenditure does not fall within their budgets and/or is treated as pertaining to decisions specific to lines of business

In this framework, Green IT type approaches focused on optimizing the energy performance of devices, architectures, applications and digital services[28] are certainly useful but no longer sufficient.

We have therefore sought to identify levers of action more closely related to the demand and consumption of digital services than on the energy efficiency of supply. **They could perfectly well be entrusted to a CIO, though their activation involves the commitment of corporate management, and relies on the principle of digital sobriety which it must validate and promote.**

The first objective of these levers is **to illustrate with quantitative examples** the impact that a digital sobriety approach can have when implemented by a company.

The second is to provide the first prototype of the **methodology for quantifying** the effects of a digital sobriety action. This type of methodology can be used by a company, adapted to the specific needs of its activities and used to predict the effect of a decision on the annual environmental impact of its digital activities.

The calculations and results presented in this deliverable have an illustrative value and are not exhaustive. Their validity is, of course, bound to the set of hypotheses chosen, explained in full here and easily modifiable[29].

a. Scope of recommendations

The recommendations presented here propose **examples of operational measures that can be implemented by companies using digital technologies to reduce the environmental impacts of their digital ecosystem.**

By "companies using digital technologies", we exclude companies whose main activities consist in producing digital devices and/or operating digital services. Thus, the levers have been designed by taking into account the company only from the angle of "user of the devices and services supplied to them", so as to involve the largest possible number of structures. In addition, the term "company" is used but these recommendations can be applied or easily adapted to any type of organization: pubic institutions, private bodies, hospitals, associations, etc.

b. Calculation methodology

The levers presented have been selected to be as pertinent as possible on the operational level: **the goal is to provide an approach and proposals that the decision-making bodies of the company can easily make their own.** This selection is therefore based on the lever's facility of operational application, its pertinence in the light of the magnitude of the effect it can produce and the possibilities of characterizing its effects through quantitative magnitudes.

Each lever also brings into play concrete assets for the company and its employees: number of smartphones, computer installations, file-sharing server, etc.

Each of the levers has been subjected to a quantification based on data consolidated in the Digital Environmental Repository (DER)[30]. The "quantification" of the lever effect corresponds to an evaluation of the reduction in the annual environmental impact of the item concerned, brought about by activating the lever.

[27] The question of knowing if and how the digital transition can reduce the carbon footprint of a company is not dealt with in this chapter.
[28] See in particular: Alliance Green IT (AGIT). (2017). *Livre Blanc - L'écoconception des Services Numériques*. http://alliancegreenit.org/wp-content/uploads/Doc%20AGIT/LB-ecoconception-numerique.pdf
[29] All the hypotheses are set out in Appendix 5: Methodological note "Corporate Levers".
[30] cf. III. The Digital Environmental Repository.

This environmental impact is represented by GHG emissions in this exercise. They act as an indicator common to production and utilization phases in our project – a characteristic required to formulate the calculations[31] – and reasoning in terms of annual emissions simplifies contextualizing these results in approaches based on Carbon Footprint type approaches.

This reduction is calculated as a relative decrease (in %) of the impact between a reference situation (initial situation, representing the real present situation) and a modified situation (situation in which the lever is implemented and its effect obtained, as all things not directly influenced by the lever are considered unchanged), for the item of emission concerned.

c. Levers no.1 & no.2: Lengthening the lifetime of professional devices

1. Statement and objectives of the lever

One of the main components of a company's digital ecosystem is the quantity of devices it makes available to its employees.

Professional digital equipment is now at the heart of corporate policies and especially digital transformations, of which the generalized integration of teleworking in companies is a good example.

Policies to regularly renew these items of equipment are an integral part of managing a company's reactivity on the technical level – in view of the functionalities provided by the equipment – but they also participate in strategies related to the company's image: **thus, increasingly, professional digital devices are becoming more standardized and the renewal of all the equipment occurs independently of the functional status of each device.**

The renewal of equipment is a problem with quantitatively major implications, not only on the environmental level, since the renewal of equipment involves impacts linked to the production phase, but also at the level of the device management process. **Increasing device lifetime permits both reducing the environmental impact of the company's activities and alleviating the management process linked to renewal, thus two effects contributing to overall sobriety.**

Levers 1 and 2 recommend increasing the lifetime of items of professional equipment given the importance of the production phase in the global impact of terminals and on their entire lifecycles[32].

The two items of equipment are the smartphone and the laptop computer.

2. Hypotheses

The average respective lifetimes of the items of equipment in the reference situation are estimated at 3 years for a laptop computer and 2.5 years for a smartphone. They were chosen so as to be consistent with the reality of the situation in companies[33].

The lever proposes to lengthen these lifetimes to 5 and 3.5 years, respectively.

[31] cf. Appendix 5: Methodological note, "Corporate levers"
[32] cf. III. The Digital Environmental Repository
[33] cf. Appendix 5: Methodological note, "Corporate levers"

3. Results

Intra-company levers		
Lever N°	1	2
Lever description	Increasing the lifetime of professional laptops from 3 to 5 years.	Increasing the lifetime of professional smartphones from 2.5 to 3.5 years.
Annual reduction of related GHG emissions (%)	-37%	-26%

Table 10: Quantification of the effect of Corporate Levers no.1 and no.2, Synthesis.
[Source: "[Lean ICT Materials] QuantiLev". Produced by The Shift Project]

Increasing the lifetime of devices is a direct and fairly simple lever to implement in association with a change in maintenance contracts and in the rules of depreciation accounting of equipment.

It permits reducing by 25% to nearly 40% the annual impact of two key items of a company's digital ecosystem (Table *10*). For an employee equipped with a professional smartphone and laptop computer supplied by their company, activating the lever will lead to a reduction of the annual environmental impact of their equipment by almost a third.

d. Lever no.3: Increase the BYOD share of BYOD smartphones

1. Statement and objectives of the lever

Lever 3 proposes setting up a BYOD (bring your own device) policy within the company, based on the utilization of smartphones equipped with two SIM cards. The objective is to combine personal and professional uses in the same terminal to reduce the number of professional smartphones: since professional uses represent only a fraction of the equipment's use, the volume of professional smartphones will become a fraction of the real number of terminals.

The objective is therefore focused on the same type of issue as levers 1 and 2, since it entails acting on the number of professional devices in order to reduce the number of devices produced to satisfy the same final needs of the employees and the company.

2. Hypotheses

The initial situations and with levers are determined through the rate of professional smartphone ownership. In the initial situation, the rate is composed of 20% of smartphones operating with a double-SIM system and a "pro-personal" offer, as the rest of ownership is composed of smartphones wholly dedicated to professional use. In the lever situation, the proportion of "pro-personal" smartphones increases to 70%, while that of smartphones used wholly for professional purposes decreases as a consequence.

Although these definitions were chosen to represent an initial situation with an achievable lever, they do not pretend to describe an average of companies or a standard situation. Since the contexts of companies vary considerably, the aim here is to provide an example to illustrate a magnitude of the impact that this lever of sobriety would have on the environment.

The "pro-personal" user profile is defined as the addition of professional and personal user profiles on the same terminal: we consider that assigning two types of use to the same terminal would not lead to an effect of substitution between them. In addition, we consider that this would not impact the lifetime of the terminal, assumed here to be 2.5 years, since smartphones are often replaced for questions of functionalities more than due to wear, as discussed for levers 1 and 2[34].

[34] cf. Levers no.1 & no.2: Lengthening the lifetime of professional devices

3. Results

Intra-company levers	
Lever N°	3
Lever description	Increasing the BYOD share of smartphones from 20 to 70%.
Annual reduction of related GHG emissions (%)	-37%

Table 11: Quantification of the effect of Corporate levers no.3, Synthesis.
[Source: "[Lean ICT Materials] QuantiLev". Produced by The Shift Project]

The simulation of the effect of lever no.3 shows a reduction of annual emissions associated with the total number of professional smartphones in use of 37%. This means that combining professional and personal uses on the same terminal reduces the impact of the device by a fraction well over one third, which can be explained once again by the importance of the production phase in the total impact of the equipment.

This lever may lead to certain difficulties of implementation according to the situation of the company. Indeed, it is necessary to deal with certain issues when professional resources are accessible on a personal device: issues of data security, managing the variety of devices (compatibility and certification of applications developed by the company, for example), corporate ethics (right to switch off).

However, solutions have already been developed (securing and tracking professional data, separation of professional applications on a personnel terminal, etc.) and actors specialized in these problems are developing the tools required to implement them.

1. Hypotheses

The display screens are assimilated with the "connected TV" equipment described in the Digital Environmental Repository (DER): professional display devices are in effect similar if not the same as equipment intended for the general public.

The hypotheses and results used in the calculations are therefore taken directly from the DER for connected TVs, whose impact is considered here through their production and utilization phases.

e. Lever no.4: Favoring the exchange of office documents on a shared platform

1. Statement and objectives of the lever

Data storage (whether on a local server of hosted by an external provider) participates in the environmental impact of the company, since it relies on using the resources of data centers whose environmental impact are known[35].

The objective of this lever is to present a concrete example of the methodology to be applied to limit the data exchanged as much as possible to data whose exchange is vital. To do this, it positions itself from the standpoint of data storage and considers an example of data generated by collaborative work: the lever proposes to reduce the number of copies of the same document stored on the servers used by the company (whether they are located in an internal or external data center), by privileging the exchange of documents via a platform synchronized with a shared server – such as Dropbox, Sharepoint, OneDrive etc. – rather than by email.

2. Hypotheses

To quantify the impact of this lever, we use a case study: five employees work on the same document of 1 MB, which they share in four successive versions.

[35] cf. III. The Digital Environmental Repository

Three scenarios can be compared:

Scenario 1 – initial situation, all the versions of the document are shared by email.

Scenario 2 – realistic objective, where the exchange is distributed equitably (50% of exchanges) between the synchronized platform and exchanges by email.

Scenario 3 – ideal case, where the exchanges are made exclusively with the platform.

In these three scenarios, we consider that each contact shares all the versions of the document (by email or via the platform) and that they save all the attachments received on their terminal. The hypothesis is also formulated that the terminals used by the contacts are synchronized with a backup server linked to the company, on which the attachments received are copied once only. We also consider that the server used by the information sharing platform is copied once[36].

For each scenario, we consider the emissions generated by sending emails and those generated by storing the different copies of the document. The reduction of the impact generated by implementing the lever is calculated on the basis of the difference between the emissions associated with Scenario 1, taken as the reference, and those associated with Scenarios 2 and 3, the objective of the lever and the ideal scenario.

3. Results

Intra-company levers		
Lever N°	4	
Lever description	Favoring the exchange of office documents on a shared platform.	
Scenario	2 (target)	3 (optimum)
Annual reduction of related GHG emissions (%)	-40%	-81%

Table 12: Quantification of the effect of the Companies lever no.4, Synthesis.
[Source: "[Lean ICT Materials] QuantiLev". Produced by The Shift Project]

The results of simulating the effect of lever no.4 show the reduction of annual emissions associated with the collaborative work described in this case study, which can be expected by a simple modification of utilization. This lever is very simple to implement, since it does not require any adaptation of infrastructures or of the company's processes, simply that of how they are used (most companies in fact already use a synchronized sharing platform, either locally or internally). In this case, we have simply modified the vector of file sharing and the number of previous versions archived.

The 40% reduction obtained for the intermediate scenario, the objective of the lever, results from reducing the two contributions to emissions: sending the emails and their attachments and storing copies of the document on the servers used by the company. This substantial reduction of impact shows that the issue of the non-controlled increase in the volume of data exchanged observed over recent years[37] is not only linked to the evolution of digital needs: **a large proportion of this volume can be reduced without impacting functionalities or performance, but simply by modifying modes of usage.**

f. Lever no.5: Implementing operational metrics

1. Statement and objectives of the lever

This entails **determining metrics that can be easily understood by the different decision-making levels and usable for arbitrating projects having a digital dimension.**

[36] Detailed in Appendix 5: Methodological note on "Corporate levers"

[37] cf. II. Challenges and observations

These metrics, standardized at least within the company, are **indicators of the environmental impact of the digital component(s) of a product, destined to be taken into account among the selection/optimization criteria (in the same way as financial and social criteria) of the project or product.**

Thus it becomes possible to apply the principle of digital sobriety far upstream of the sequence of operational decisions that will result in the acquisition of digital equipment and in the use of digital services having an impact on the company's carbon balance.

The simulation performed for lever no.5 presents **an example of metrics to illustrate this approach in the framework of projects involving the installation of the display screens that have blossomed over the last few years in the corridors of companies, shopping malls and in the streets of towns.** Thus, the lever focuses on the construction of the metric "environmental impact of a display screen as a function of its size".

2. Results

Intra-company levers	
Lever N°	5
Lever description	Implementing operational metrics.
Average screen size (inches)	55
Annual related GHG emissions (kgCO2e)	106
Metric: impact of the size of a screen ($kgCO_2e$/an/inch)	2

Table 13: Quantification of the effect of Corporate lever no.5, Synthesis.
[Source: "[Lean ICT Materials] QuantiLev". Produced by The Shift Project]

The example of display panels was chosen to show that this type of metric can be very simple to develop: in this case, we could build this tool by combining a rigorous correlation of the devices used by the company with the data available and already produced of a carbon balance or resulting from a DER type approach.

One of the possible contexts of application for this metric is the arbitration of a strategy to deploy display screens. This type of deployment concerns the in-house communication of companies, on a small scale, but also includes actions of a much larger scale for external communication, for example by hypermarkets and public transport companies. The deployment of advertising screens has become widespread in recent years, driven by considerable investments.

Having a measurement of the average environmental impact of a screen according to its size allows facilitates and concretely includes the objective of digital sobriety in the arbitration intended to identify an optimized solution: what size and what quantity of devices to satisfy needs while minimizing the carbon impact?

We can see here the advantage of developing this type of standardized metrics, at least at the level of a company, and they would allow, for example, eventually building tools capable of characterizing the "environmental impact of one euro of investment" for a given digital transformation.

V. Digital sobriety and developing countries

Photo credit: UIT

a. Digital technology in developing countries

1. The penetration of digital technology

Although the statistics confirm the widely held opinion that smartphones are already present in every region of the world, the digital reality is more complex than it seems.

A symbol of the dynamics of globalization, **the rate of smartphone ownership in the developed countries is currently around 80%** and smartphones are used daily even by the most disadvantaged sectors of populations:

"In developing countries, the households that own a smartphone are more numerous than those who have access to electricity or clean drinking water, and nearly 70% of persons belonging to the lower quintile of the population own a smartphone." (World Bank, 2016)

Although the relatively low cost and short lead-times for building cellular infrastructures have allowed compensating the almost non-existence of fixed infrastructures in only fifteen years, **a large number of cell phones can only communicate via networks based on 2G technology which does not allow using the Internet**:

"…nearly 60% of the world's population still does not have access to the Web and has no practical way of participating in the digital economy." (World Bank, 2016)

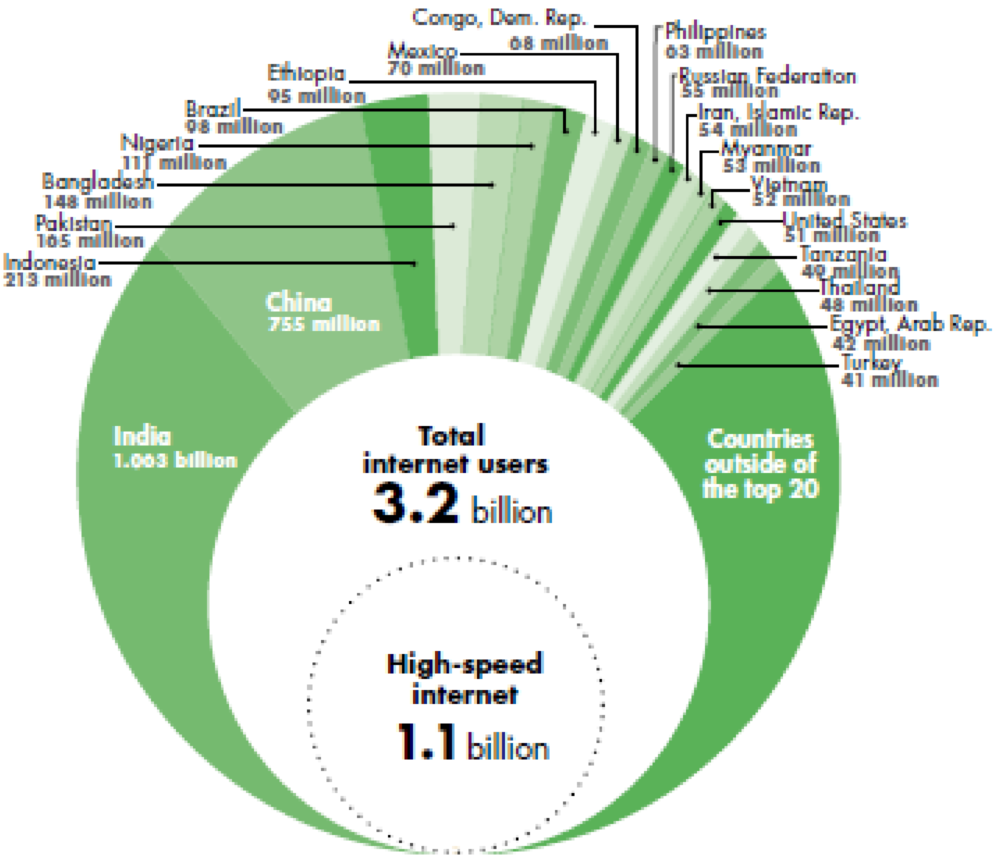
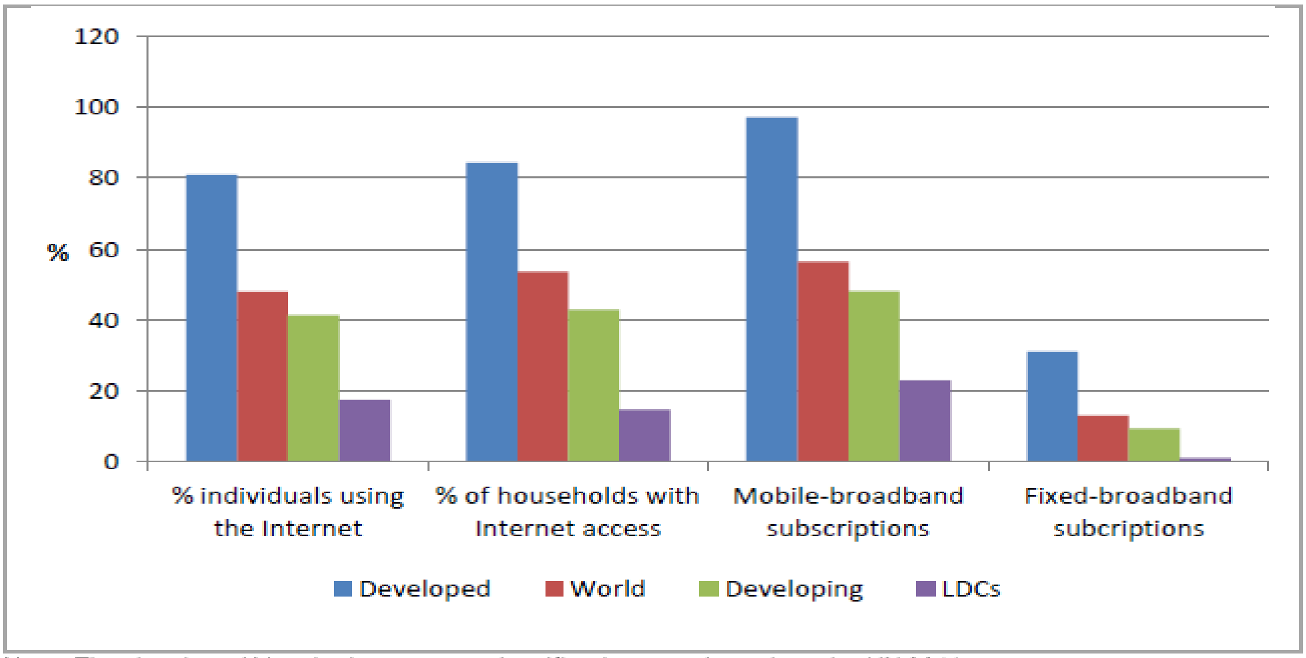


Figure 17: World non-connected population.
[Source: (World Bank, 2016)]

This proportion of **"digitally excluded"** is as high as the development of the country is low[38]; it rises to **more than 80% for the least developed countries**:



Note: The developed/developing country classifications are based on the UN M49, see:
http://www.itu.int/en/ITU-D/Statistics/Pages/definitions/regions.aspx.html
Source: ITU[8]

Figure 18: Access to ICTs by development status, 2017 estimates
[Source: (Sirimanne, 2017)*]*

[38] Cf. Appendix 6: Least Developed Countries

But the lack of infrastructures providing broadband access is not the only reason for this exclusion: "*Whereas many people still live outside the range of 3G or 4G signals, most non-connected persons come up against other obstacles such as network performance, fairly high connection costs, and the electric recharging of cell phones*[39] *and devices, the lack of locally pertinent content and poor digital culture.*" (GSMA, The Mobile Economy, 2018, p. 38)

Thus, although the lack of adapted infrastructures (3G network or better) is clearly to blame in the least developed countries, other factors can be pointed to in developing countries:

- **Price of internet use** out of phase with purchasing power;
- **Non-existence or insufficient content generated locally** or translated into the local language and accessible via the internet;
- Capacity to **master digital interfaces** (therefore, first of all know how to read and write)[40].

As shown by the following figure:

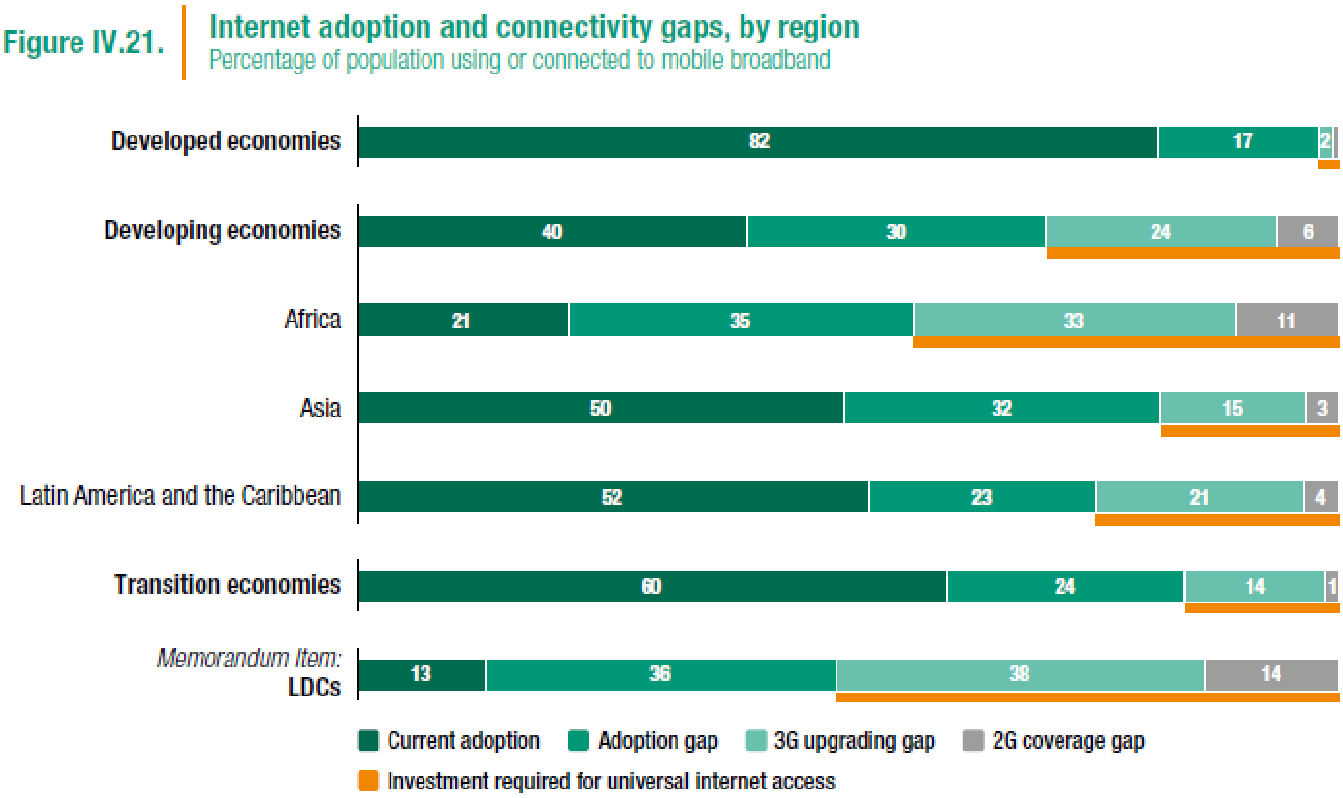


Figure 19: Internet adoption and connectivity gaps, by region (percentage of population using or connected to mobile broadband *[Source: UNCTAD, World Investment Report 2017, page 197]*

2. Digital technology as a lever for development

The 2030 Sustainable Development Agenda and its 17 Sustainable Development Goals (SDG), approved in 2015 by all the world's leaders, **expressly acknowledged the potential of information and communication technologies for sustainable development**: *"The dissemination of information and communication technologies and world interconnection have great potential for accelerating human progress, filling the digital divide and developing knowledge societies."* (United Nations, 2015).

More specifically, connectivity was the subject of SDG 9.c which aimed at *"considerably increasing access to information and communication technologies and striving to provide universal and affordable access to the internet in the least developed countries from now to 2020."*.

This promulgation of the importance of digital technology on the development agenda dates from the beginning of the 2000s: in 2003 at Geneva then in 2005 at Tunis, the **international conferences of the World Summit for the Information Society** (WSIS) sponsored by the United Nations (UNESCO, UIT, UNCTAD, PNUD) identified the principles and challenges of building the information society.

[39] In areas not covered by electricity grids, the monthly budget can amount to €3, including €1 for the electricity and €2 for communications, while the monthly wage is less than €30.
[40] About 40% of the population in developing countries is illiterate. (UNESCO, 2017)

The WSIS Forum has been held annually since then and serves as a platform for discussing the role of digital technologies as a means of reaching the goals and targets of sustainable development, by now taking account of the 2030 Sustainable Development Agenda.

A matrix summarizes the (many) contributions expected from digital technology to reach the different SDGs, shown in the figure below (Figure 20). 18 initiatives were identified (cf. Figure 21).

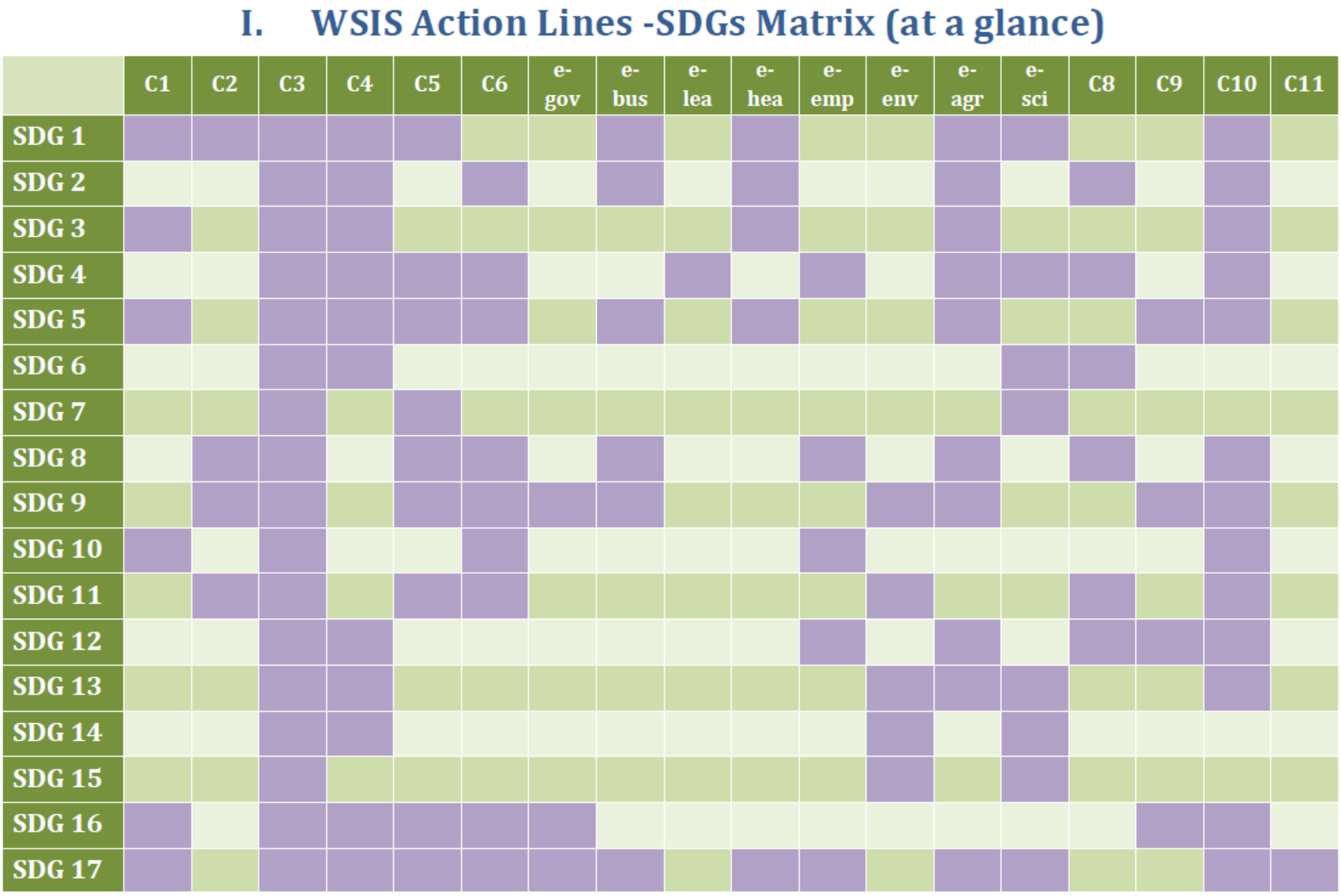


Figure 20: WSIS Action lines – SDGs Matrix -at a glance- (1)
[Source: (WSIS, 2015)]

WSIS Action Lines	SDGs
C1: The role of governments and all stakeholders in the promotion of ICTs for development	Goal 1, 3.8, 3.d, Goal 5, 10.c, 16.5, 16.6, 16.10, 17.18
C2: Information and communication infrastructure: an essential foundation for the Information Society	1.4, 8.2, 9.1, 9.a, 9.c, 11.5, 11.b
C3: Access to information knowledge	Goal 1, Goal 2, Goal 3, Goal 4, Goal 5, Goal 6, Goal 7, Goal 8, Goal 9, Goal 10, Goal 11, Goal 12, Goal 13, Goal 14, Goal 15, Goal 16, Goal 17
C4: Capacity building	1.b, 2., 3.7, 3.b, 3.d, 4.4, 4.7, 5.5, 5.b, 6.a, 12.7, 12.8, 12.a, 12.b, 13.2, 13.3, 13.b, 14.a, 16.a, 17.9, 17.18
C5: Building confidence and security in the use of ICTs	1.4, 4.1, 4.3, **4.5**, 5.b, 7.1, 7.a, 7.b, 8.1, 9.1, 9.c, 11.3, 11.b, 16.2, 17.8
C6: Enabling environment	2.a, 4.4, 5.b, 8.2, 8.3, 9.1, 9.c, 10.3, 11.3, 11.b, 16.3, 16.6, 16.7, 16.10, 16.b, 17.6, 17.14, 17.16
C7 ICT Applications: i. e-government	9.c, 16.6, 16.7, 16.10, 17.8
C7 ICT Applications: ii. e-business	1.4, 2.3,5.b, 8.3, 8.9, 8.10, 9.3, 17.11
C7 ICT Applications: iii. e-learning	Goal 4
C7 ICT Applications: iv. e-health	1.3, 1.4, 1.5, 2.1,2.2,Goal 3, 3.3, 3.8, 5.6, 5.b, 17.8, 17.19
C7 ICT Applications: v. e-employment	**4.5**, 8.5, 10.2, 12.6, 17.9
C7 ICT Applications: vi. e-environment	9.4, 11.6, 11.b, 13.1, 13.3, 13.b, Goal 14, Goal 15
C7 ICT Applications: vii. e-agriculture	1.5, 2.3,2.4,2.a, 3.d, Goal 4, 5.5, 8.2, 9.1, 9.c, 12.8, 13.1, 13.3, 17.16, 17.17
C7 ICT Applications: viii. e-science	1.5, 4.7, 6.1, 6.a, 7.a, 13.1, 13.2, 13.3, 14.a, 15.9, 17.6, 17.7
C8: Cultural diversity and identity, linguistic diversity and local content	2., 4.7, 6.b, 8.3, 8.9, 11.4, 12.b
C9: Media	5.b, 9.c, 12.8, 16.10
C10: Ethical dimensions of the Information Society	1.5, 2.3,3.8, 4.7, 5.1, 8.36, 9.1, 10.2, 10.3, 11.3, 12.8, 13.3, 16.7, 16.10, 17.6, 17.7, 17.8, 17.18, 17.19
C11: International and regional cooperation	17.9, 17.16, 17.17

Figure 21: WSIS Action lines – SDGs Matrix -at a glance- (2)
[Source: (WSIS, 2015)]

Paradoxically, **only 3 of the 244 indicators of SDGs concern digital technology** (Ducass, 2018):

- indicator 5.b.1: proportion of the population owning a cell phone, by gender;
- indicator 9.b.1: proportion in the total added value of medium and high technology;
- indicator 17.6.2: subscriptions to a fixed broadband internet connection per 100 people, by connection speed.

3. The outlook for 2025

Growth in cellular phone ownership should continue to be strong in the next few years, as telecom operators see developing countries as one of their main sources of growth (together with 5G and IoT in developed countries). (GSMA, The Mobile Economy, 2018)

From now to 2025, the penetration of the mobile internet should increase by 50% and reach 61% of the world's population. The greater part of the increase (1.75 billion) in new mobile internet users between 2017 and 2025 will come from **China** (about 350 million new users), **India** (330 million) and **Sub-Saharan Africa** (280 millions).

In terms of number of mobile connections, **4G will become the leading technology of the mobile network in 2019 (with more than 3 billion users) and will still be ahead in 2025**. This boom will coincide with the near disappearance of 2G technology networks, including in developing countries. Out of the 2.5 billion new 4G connections during the next eight years, 1.1 billion will come from the three main Asian markets (India, China and Indonesia) and 1 billion others will come from South America, the Middle East, North Africa and Sub-Saharan Africa. Service to rural regions will also be facilitated by the gradual deployment in the next ten years of low orbit satellite projects (SpaceX, OneWeb, O3b).

Thus, 4G networks will predominate in India, associated with a growth in smartphone adoption of nearly 70%:

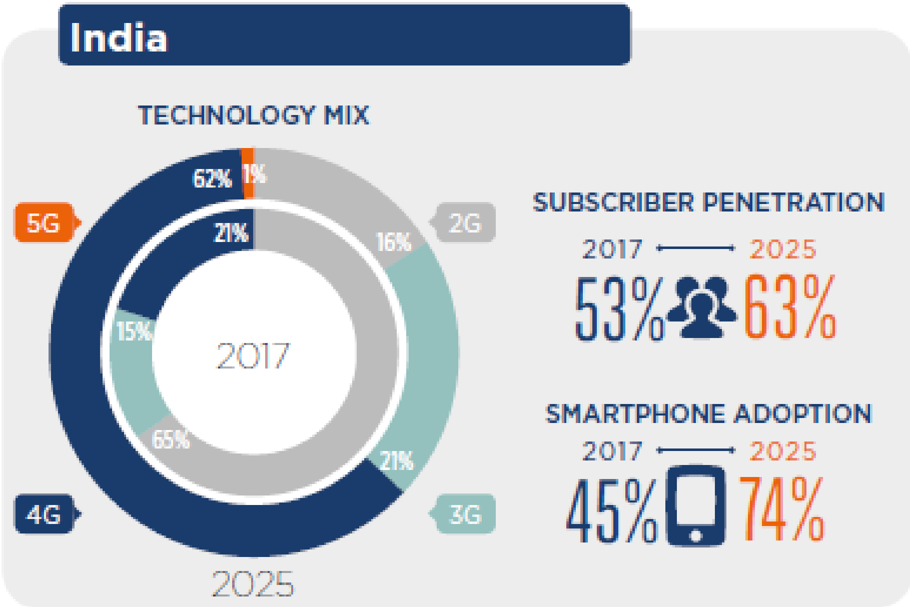


Figure 22: Smartphone penetration in India.
[Source: (GSMA, 2018)]

In Sub-Saharan Africa, 3G will predominate, leading to a twofold increase in the population having access to the Internet:

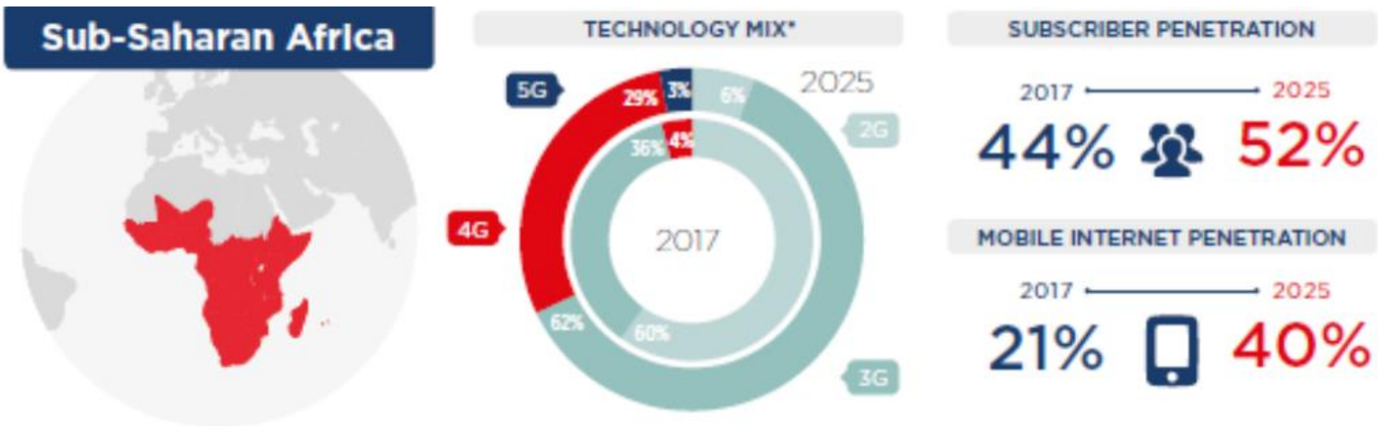


Figure 23: Smartphone penetration in Sub-Saharan Africa.
[Source: (GSMA, Global Mobile Trends, 2017)]

This evolution of networks will be linked to an explosion in the number of smartphones in developing countries, resulting from the success of low-cost smartphones, such as those produced by Huawei, Oppo, OnePlus and Xiaomi in China, Micromax in India, and AfriOne in Nigeria.

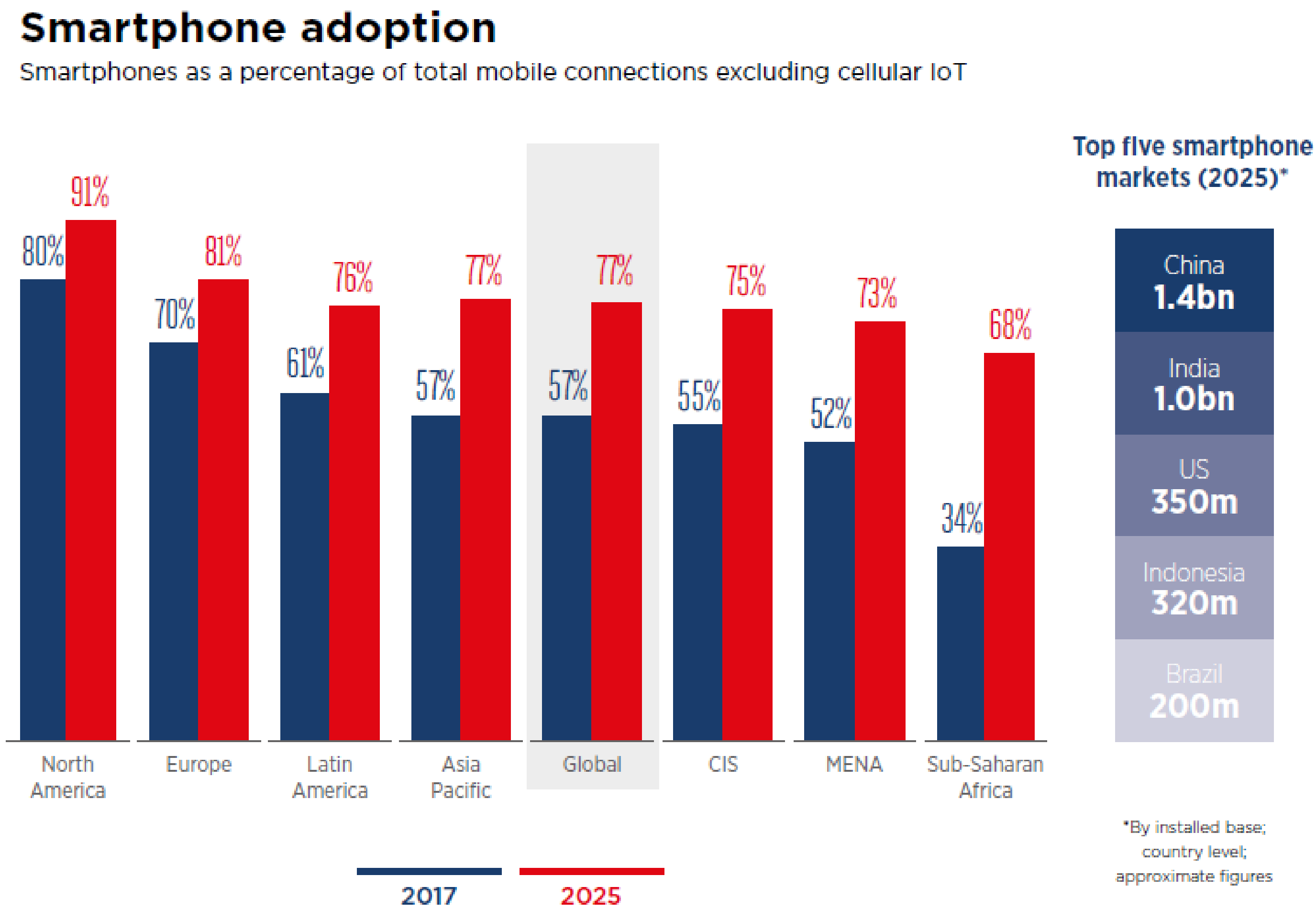


Figure 24: Smartphones as a percentage of total mobile connections excluding cellular IoT
[Source: (GSMA, The Mobile Economy, 2018)]

4. Investment policies with as yet little detail

Table IV.3. Announced greenfield FDI projects in ICT infrastructure, by destination region, 2012–2016

Destination region	Number of projects	Jobs		Capital investment	
		Total	Average	Total (Millions of dollars)	Average (Millions of dollars)
Africa	145	11,337	78	24,877	171.6
Asia	357	27,121	76	36,612	102.6
Latin America and Caribbean	186	17,456	93	54,496	293.0
Transition economies	42	3,642	86	2,401	57.2
Total	**730**	**59,556**	**81**	**118,386**	**162.2**

Source: ©UNCTAD, based on information from Financial Times Ltd, fDi Markets (www.fDimarkets.com).

Figure 25: Foreign investments in digital infrastructures.
[Source: (UNCTAD, World Investment Report 2017, 2017) p. 195]

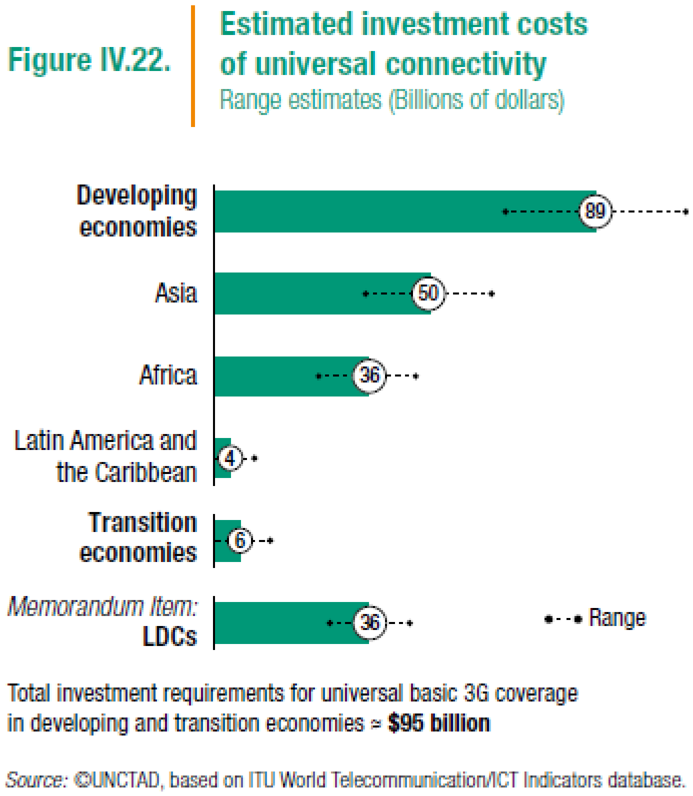


Figure 26: Estimated investment costs of universal connectivity.
[Source: (UNCTAD, World Investment Report 2017, 2017, p. 198)]

Although major investments in infrastructures have been made over recent years (cf. Figure 25), and a comparable financial effort remains to be made in Asia and above all Africa to make broadband accessible to all (cf. Figure 26), **the investments needed for the "Digital Transition" of developing countries are often insufficiently quantified** and detailed in the strategic plans implemented by governments (UNCTAD, 2017):

"Many countries have published or are preparing strategies to develop the digital economy. However, most digital development strategies do not adequately document investment requirements, and those that do often focus exclusively on investment in infrastructures (broadband coverage), and very little on the potential role of foreign investment or API. A global digital development strategy should cover investments in infrastructures and digital companies, and in those required by companies for their digital transition.

[…] Many digital development strategies fail to broach the issue of investment or mention investment needs in only a very general way. Less than 25% include details on needs to invest in infrastructure, and less than 5% on investments needs beyond the infrastructure, including for the development of digital enterprises. Investment promotion agencies are seldom involved in formulating digital development strategies."

5. Mastering the digital revolution

As identified by the World Bank as early as 2016, **the structural effects of digital technology are not necessarily always positive or negative**, including in developing countries (World Bank, 2016):

"Digital technologies stimulate productivity and improve the general well-being, but the disturbances they cause on the job market can be detrimental and lead to increased inequality […] An associated trend is the polarization or erosion of the job market that can be seen not only in developed economies, but increasingly in many developing countries. The proportion of jobs reserved for highly qualified and poorly qualified persons is increasing while that of semi-qualified jobs is decreasing in most developing countries for which we have detailed data." (World Bank, 2016, p. 33)

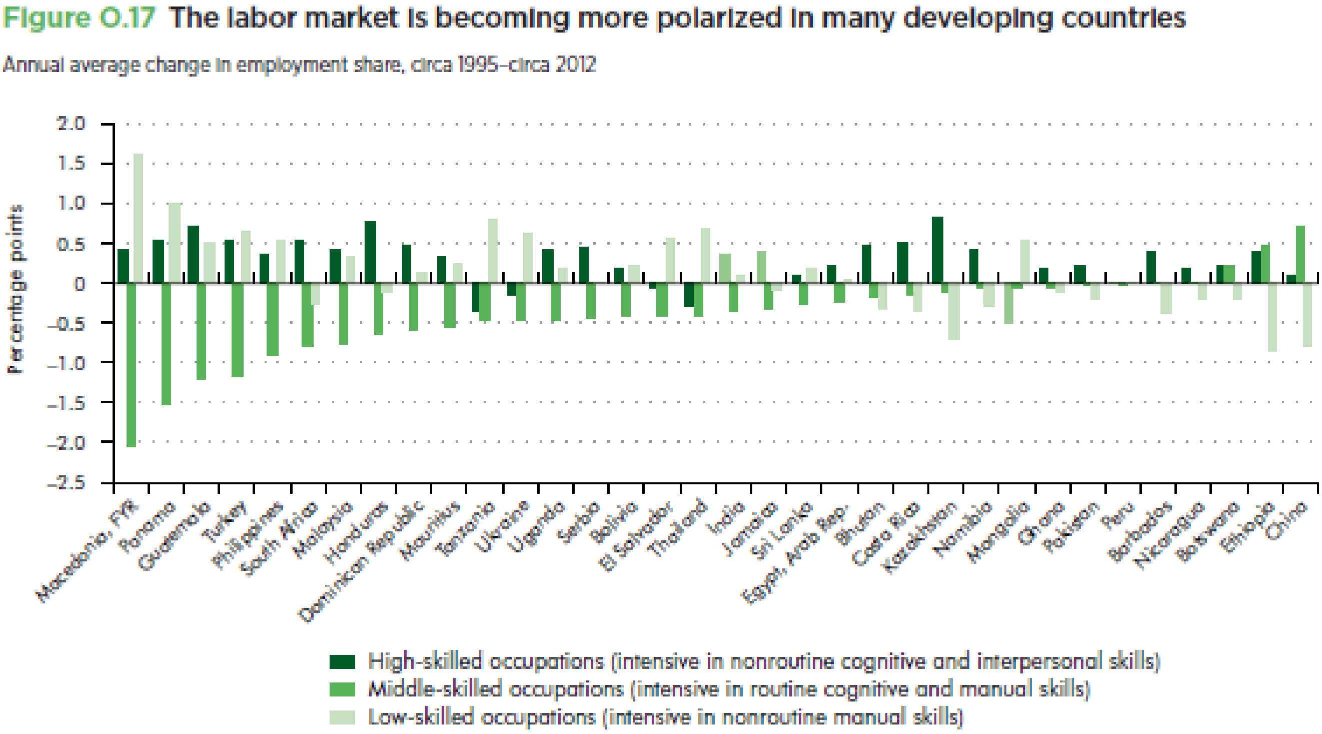


Figure 27: The job market is increasingly polarized in many developing countries.
[Source: (World Bank, 2016, p. 22)]

And again:

"Although there are plenty of examples of individual successes, the effects of digital technology on world productivity, the improvement of opportunities for the poor and the middle class and the promotion of the ethics of responsibility in managing public affairs have not matched expectations. Companies are more connected than ever, but world growth and productivity have slowed down. Digital technologies transform the world of work, but job markets have polarized and inequalities are growing, especially in the richest countries, though also in developing countries. And whereas the number of democracies is increasing, the proportion of free and regular elections is waning." (World Bank, 2016, p. 14)

The same alarm call was sounded by the UN:

" "It is true that digitization provides fine opportunities for development, but if we enter the movement blindly, we will not be able to take advantage, quite the contrary", warned on Monday the United Nations Conference on Trade and Development (UNCTAD) when launching the fourth edition of the Electronic Trade Week."[41]

And again:

"However, the UNCTAD also observed in its report that the dissemination of new technologies is so fast that society – and decision-makers – may well be incapable of adapting to the radical changes that occur with it. What is more, advanced technologies can aggravate existing economic, social and technological imbalances and exacerbate inequalities." (UNCTAD, Press release, 2018)

It is therefore clear that **digital transition must occur with structural measures** – especially public policies – that allow controlling its impacts and make it a genuine catalyst for sustainable development:

"Connectivity is essential but not enough to harvest all the fruits of digital technologies. Investments in digital technologies must be supported by "analog supplements": regulations that allow companies to use the internet to face competition and innovate; better skills so that individuals can grasp all the potentialities provided by digital technologies; and supervisory institutions, so that the public authorities respond to citizens' needs and demands. Digital technologies could in turn strengthen these supplements, and speed up the pace of development."(World Bank, 2016)

[41] Isabelle Durant, Deputy General Secretary of the UNCTAD, 16 April 2018. On https://news.un.org/fr/story/2018/04/1011212, consulted on 19/09/2018

Nonetheless, these reforms will take many years to provide results whereas the pace of technological change never ceases to accelerate.

Hence the necessity for international funding bodies to give particular attention to **reposition support for Digital Transition within a holistic approach**:

"UNCTAD recommends concerted international action to develop technological competences and support all forms of innovation in developing countries. The least advanced countries, in particular, should benefit from international support when they seek to strengthen their capacities and create an environment that will allow them to benefit from leading edge technologies." (UNCTAD, Press release, 2018)

b. Digital technologies and the environment

1. Institutional context

Although the need to manage and anticipate the social and cultural impacts of digital transition has been identified, **its interaction with the issues of energy transition and climate change has not been taken into account** at this juncture in the formulation of investment policies, including in the most recent recommendations of the United Nations (Figure *28*).

Table IV.9. Policy framework for investment in the digital economy

		Policy checklist
Strategic investment policy considerations		▸ Review competitive advantages for the attraction of investment from digital MNEs, assess potential challenges and risks, and identify strategic opportunities (e.g. niche industries, digital content or services industries, app development). ▸ Review and prepare for changing investment determinants and investor profiles in other industries as they adopt digital technologies in global supply chains. ▸ Formulate a strategic response to ensure investment policy remains geared towards sustainable development and inclusive growth.
Embedding digital development in investment policies	National	▸ Assess the extent to which existing investment regulations are affected by digital operating models. ▸ Modernize investment regulations where needed, balancing investment promotion and facilitation with measures to mitigate risks associated with digital operating models.
	International	▸ Review the coverage and treatment of new digital industries in IIAs. ▸ Take into account the digital investment dimension of evolving international rules, such as those on e-commerce and services trade.
Embedding investment policy in digital development strategies	Invest in digital infrastructure	▸ Conduct a detailed assessment of infrastructure investment needs in digital development strategies, including broadband coverage and internet infrastructure (e.g. data centres, IXPs). ▸ Build the right conditions for private investment in digital infrastructure, including to promote public service and universal connectivity objectives. ▸ Engage in regional cooperation, promoting multi-country infrastructure investments for scale.
	Invest in digital firms	▸ Ensure that content rules and regulations remain conducive to investment in the digital sector, while safeguarding public policy objectives. ▸ Support local enterprise development in the digital economy, through clusters and hubs, facilitation of innovative financing approaches, and conducive regulations in non-digital industries.
	Invest in digitalization	▸ Promote investments by firms across all sectors in ICTs and in related skills, and access to low cost digital services (e.g. cloud services). ▸ Build and improve e-government services to lead the way, to create demand for local developers, and to lower the cost of doing business.
Policy interactions and institutional synergies		▸ Manage interactions with related policy areas to address public concerns, through up-to-date regulations (e.g. data security, privacy, competition, consumer protection, national security, safeguarding of cultural values). ▸ Manage interactions with sectoral and social policies to mitigate potential negative social and economic impacts of digital transformation (e.g. job losses in traditional sectors). ▸ Ensure an effective whole-of-government approach, establishing coordination processes and communication channels across institutions, and involving investment authorities and IPAs.

Source: ©UNCTAD.

Figure 28: Policy framework for investment in the digital economy
[Source: (UNCTAD, World Investment Report 2017, 2017, pp. 189, 216)]

As is often the case, it appears that many international organizations consider that digital technologies do not raise environmental issues, and even that any investment of this kind or any utilization is **necessarily beneficial on this level, including from the standpoint of climate change and the depletion of natural resources:**

"Goal 13: Climatic action.

Digital technologies can contribute to mitigating climate change and to adapting to these changes. It has been estimated that efficient use of ICTs will lead to a global reduction in CO_2 emissions of 15%. Information and communication technologies can also be used to monitor the impacts of climate change. For example, a special combined team of the UIT, the World Meteorological Organization and the United Nations Education, Science and Cultural Organization is studying the use of underwater telecom cables to monitor the oceans and climate to warn on disasters." (UNCTAD, 2017, p. 195)

"Goal 2: Achieve development within the limits of the planet.

[…] More specifically, regarding climate change, broadband and ICTs play a central role by helping to maintain humanity within this frontier thanks to an economy based on low carbon emissions based on online services rather than products. Whereas the carbon footprint of ICTs should reach 1.27 $GtCO_2e$ from now to 2020, the total potential for reduction of ICTs is seven times higher." (UNESCO I. , 2015)

"Goal 8: Slow down anthropogenic climate change and guarantee clean energy for all.

[…] The broadband solutions capable of bringing about transformation allow reinventing business models and for countries to change from technologies with high GHG emissions to development with low carbon emissions. These innovations include smart buildings, zero emission electric vehicles and online services such as online health services, online education, e-commerce, online governance and teleworking. It is estimated that mobile technology taken alone could reduce GHG emissions by 2% from now to 2020." (UNESCO I. , 2015)

The same lack of concern (lack of awareness?) about the environmental impacts of digital technology can be found in the "Principles for digital development" (see

Appendix 7: Principles for digital development, p. 82), list of good practices drawn up in recent years by international bodies following the failure of a large number of digital projects which they supported in the 2000s.

There is no mention anywhere, for example, of the environmental, political and social consequences of speeding up the extraction of metals (notably rare) needed to make digital devices, given that a major part of the production of these metals is carried out in developing countries, as is most of the electronic waste of developed countries.

Likewise, for the developed countries (although in a different context), the magnitude of GHG emissions due to digital technologies and their rate of growth demand that we do something about them, as shown by the forward approach which follows.

2. Prospective approach

It is difficult to obtain precise statistical data on all the developing countries; thus, we have limited the forward approach (horizon 2023) to two geographical areas with representative problems and whose population of 2.3 billion represents about 2/3 of the population of developing countries[42].

The adoption of internet in Sub-Saharan Africa is continuing rapidly, driven by the boom in cell phones. The number of smartphone subscribers to the internet in the region has increased fourfold since the beginning of this decade, since this technology is the only platform available capable of allowing the great majority of the population to gain access, because fixed networks are rare. During the period up to 2025, this will be the case of nearly 300 million additional people. This increase linked to the growth in the number of smartphones of 20% a year will lead to a growth in traffic of more than 60%. But in spite of this rapid growth, about 800 million people (i.e. 2/3 of the population) will remain non-connected to the Internet in 2025.

India will continue to be one of the growth engines of the smartphone market during the next few years, with an increase of more than 500 million from now to 2025 (22% of the world total). Up to then, smartphones connections in the country will make up three quarters of total connections, versus 45% in 2017. India plans to launch a massive program to deploy commercial 5G networks in 2020 to boost the performance and capacity of existing mobile networks, taking into account that the 4G networks (which only took off in 2017 due to a price war over data started by the telecommunications operator Reliance Jio) are making big advances towards general coverage. The digital divide is nonetheless considerable within the country since in 2017, 71% of the population (i.e. 950 million people) were not connected to Internet, and 50% will still remain so in 2025!

In these two regions in 2025, **video traffic** will make up more than 80% of total traffic, meaning a ratio drawing close to that of the developed countries, giving rise to needs to increase broadband on the networks and marking the convergence of uses.

Consequently, **the energy consumption attributable to digital technologies** (production and purchase of devices, electricity consumption due to utilizations) **of Sub-Saharan Africa and India will increase strongly from 2017 to 2023, by 27% and 16% a year respectively**, i.e. a growth rate three times and twice the world average respectively.

Digital energy consumption (TWh)	**2017**	**2020**	**2023**	**CAGR 2017-2023**
Sub-Saharan Africa	34	70	143	27%
India	95	142	239	16%
Total final energy consumption (TWh)	**2017**	**2020**	**2023**	**CAGR 2017-2023**
Sub-Saharan Africa	5399	5723	6066	2%
India	7267	8174	9195	4%
Digital share of total energy consumption	**2017**	**2020**	**2023**	**CAGR 2017-2023**
Sub-Saharan Africa	0.6%	1.2%	2.4%	24%
India	1.3%	1.7%	2.6%	12%

Table 14: Evolution 2017-2023 of the energy consumption of digital technologies in India and Sub-Saharan Africa.
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project]

The increase in energy consumption (all sectors) in Sub-Saharan Africa and India is much higher than the world average. But the growth of digital technology is so strong that**, if we calculate the Compounded Annual**

[42] List of "low human development" and "medium human development" countries drawn up by UNDP, on http://hdr.undp.org/en/composite/HDI, consulted on 30/09/2018.

Growth Rate (CAGR) of the digital share of the total energy consumption of Sub-Saharan Africa and India, we obtain an even higher increase:

- 24% of growth expected per year (between 2017-2023) in Sub-Saharan Africa's digital share of total energy consumption, from 0.6% of the total energy consumption in 2017 to 2.4% in 2023;
- 12% of growth expected per year (between 2017-2023) in India's digital share of total energy consumption, from 1.3% of the total energy consumption in 2017 to 2.6% in 2023.

It should be remembered that the digital share of total energy consumption is growing: in 2017 it accounted for 2.6% of the global energy consumption, and will represent 4.0% of it in 2023.

The distribution of the energy consumed by digital devices in these regions is however very different from that of the world average: **the share of energy consumed to produce devices (mainly smartphones) is 80%** whereas the world average is "only" 50%.

However, the number of communicating digital devices per capita in 2023 will remain quite modest (Cisco, VNI Mobile Forecast Highlights, 2016-2021, 2018b): 1.4 in Sub-Saharan Africa and 1.6 in India.

Thus, it is close to the world ratio (1.5) in 2011, and half of what it will be (3.2) in 2020.

And it will be a tenth of the ratio predicted in the United States in 2023, i.e. 16.2!

	2016	2021	CAGR
Asia Pacific	1.9	2.9	8.3%
Central and Eastern Europe	2.5	3.8	9.1%
Latin America	2.1	2.9	7.0%
Middle East and Africa	1.1	1.4	5.4%
North America	7.7	12.9	11.0%
Western Europe	5.3	8.9	10.9%
Global	2.3	3.5	8.5%

Source: Cisco VNI, 2017.

Table 15: Number of digital devices per capita by region.
[Source: (Cisco, 2017a)]

The aim is therefore to know how this average ratio will be distributed within each country since its increase must not widen the existing digital divide.

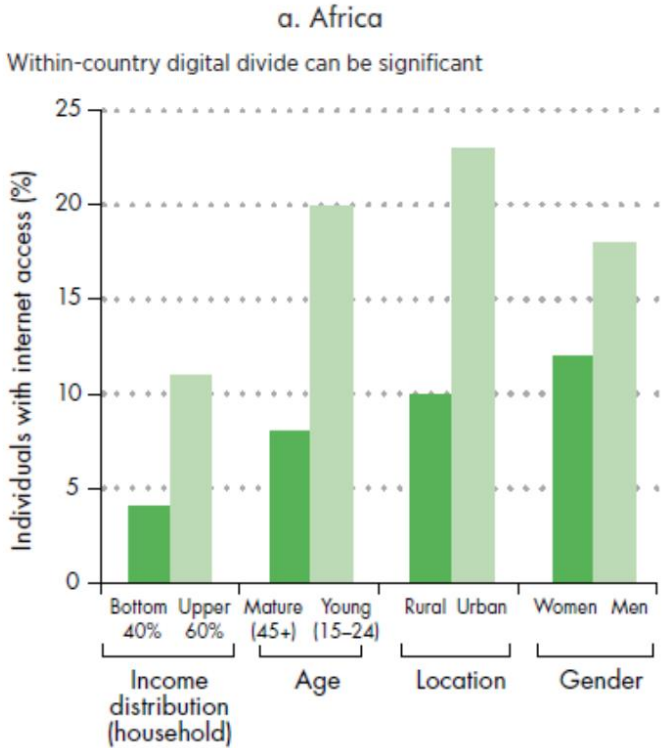


Figure 29: Disparity of access to the Internet within African countries.
[Source: (World Bank, 2016, p. 9)]

Contrary to the case of very developed countries, the growth forecast in the developing countries in the next six years will lead to a relatively low rate of device ownership.

Furthermore, **digital technology in the developing countries[43] amounts to 7% of the energy consumed in the world by this technology in 2017 and should not exceed 13% in 2023, whereas about 50% of the world's population live in these countries**.

Digital energy consumption (TWh)	**2017**	**2020**	**2023**
Developing countries	194	319	574
World	2861	3512	4486
% developing countries	7%	9%	13%

Table 16: Evolution and share of the energy consumed by digital technology in the developing countries.
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project]

On the scale of the planet and for the next 6 years, the impact of digital growth in developing countries on world energy consumption and the evolution of GHG emissions is relatively small.

The main challenge during this period clearly belongs to the (highly) developed countries.

However, the unbridled growth rate in the number of smartphones (15% to 20% a year according to country) and data traffic (30% to 60%) due to digital technology is a genuine local environmental challenge:

- A large share of the smartphone market is tapped by Chinese manufacturers which do not disclose any information on the environmental footprint of their products, an aspect that forebodes the worst rather than the best;
- The circuits for treating devices at the end of their lifecycles, at present very fragmented or non-existent, will be unable to cope with the additional load quickly enough to avoid illicit dumps and the ensuing soil pollution;

[43] List of "low human development" and "medium human development" countries drawn up by UNDP, on http://hdr.undp.org/en/composite/HDI, consulted on 30/09/2018.

- The quantity of CO_2 embedded[44] in imported smartphones is of the same magnitude as that resulting from the consumption of primary energy in the country: for example, **purchases of digital devices in sub-Saharan Africa between 2017 and 2023 amount to nearly 54% of the CO_2 emissions generated by the increase in primary energy consumption** (International Energy Agency (IEA), 2014)**.**

It is therefore vital to be able to take digital technology into account in action plans for implementing NDC (Nationally Determined Contributions) trajectories.

In 2016, the World Bank underlined in its annual report on development in the world (World Bank, 2016) the need for countries to **act on structural dimensions** (market, training, governance) to obtain the economic, social and cultural dividends from the digital investments of the next ten years.

Likewise, it is more than likely that **the environmental benefits expected from digital transition will only be obtained if the latter is driven as a function of this goal**.

To paraphrase Isabelle Durand, Deputy General Secretary of UNCTAD, we can assert that *"digital transition offers fine opportunities for the environment, it's true, but if we go about it blindly, we won't obtain any advantage, quite the contrary."*[45]

The aim of the following paragraph is to provide several tools and recommendations in view to ensuring such management, whether when defining national digital strategies or when studying specific projects.

c. Recommendations

The uncontrolled growth rate of digital technology may lead to a loss of control or/and the aggravation of existing imbalances, as revealed by UNCTAD. But two additional items make it necessary to include the environmental component in public digital strategies in developing countries:

- Without it being necessarily explicit, **projects for digital activities are considered as central in efforts to reduce GHGs**, and so it is important to verify whether the conditions required exist. Failing this, there is a real risk of failure to obtain the results hoped for, and that other paths for achieving this goal which might be efficient will be neglected.
- **The share of digital technology in investments is increasing**, including by international funding bodies. Thus, since 2014, the annual commitments of the World Bank for funding digital investments in Africa have amounted to 20% of the sums devoted to infrastructures[46] (transport, energy, water, drainage, digital technology), meaning a twofold increase in comparison to the previous decade. However, these international funding bodies now have to include the evaluation of the environmental impacts of these investments in their fund allocation processes.

Taking the environment into account in these strategies can be done by applying **four principles:**

1. **Formalize and quantify**
   The reports of the World Bank and UNCTAD established the need to formalize actions illustrating the contribution of digital technology to social, economic, and cultural development, and to quantify the investments underpinning them and the results expected. On this basis, it is both possible and essential to **formalize and quantify the environmental impacts (in particular GHG) directly linked to these investments and uses**. It is also necessary to quantify the indirect positive and negative results of digital technology on the environmental footprint of the projects of which it is a component.
2. **Prioritize**
   Digital applications are becoming increasingly diversified, although their growth is mainly driven by the supply and market power of the GAFAM (Google, Apple, Facebook, Amazon, Microsoft), and their Chinese rivals, the BATX (Baidu, Alibaba, Tencent, Xiaomi), more and more present in Asia and also in Africa. Great attention is therefore needed **to privilege digital projects whose final aim is local economic, social (health, education), and cultural development, and to incorporate environmental impacts in their evaluation**. Particular attention regarding the optimization of these impacts must be given to projects dedicated to transport, energy and construction, which are major emitters of GHGs.

[44] CO_2 emissions linked to the production phase of the terminal.
[45] Isabelle Durant, Deputy General Secretary of UNCTAD, 16 April 2018. On https://news.un.org/fr/story/2018/04/1011212, consulted on 19/09/2018
[46] The average of new annual commitments to all infrastructures has been $500m since 2014 and $100m for digital projects, on www.worldbank.org/projects

3. **Set requirements**

   Through adapted public policies (standards, taxes, etc.), it is both possible and necessary to privilege the purchase of equipment and services with a small carbon footprint and favor the extension of the amortization period of light terminals: smartphones, laptops. In public administrations and companies and/or **for projects subsidized by public funds, "lean" specifications integrating the constraints of energy sobriety should be imposed**.

   Facilitating and even imposing the **joint planning of electricity infrastructures and digital infrastructures** (networks, data centers) optimize costs and the pace of coverage of rural regions while reducing GHG emissions.

4. **Build a local ecosystem**

   Favoring the development of a local digital ecosystem is both environmentally virtuous and vital, explains the World Bank (World Bank, 2016), to obtain the dividends from digital technology: **the development of local contents (information and languages) on sites, national and regional hosting, etc**.
   Regarding devices and terminals in particular, their lifetime and utilization should be maximized for as much as possible: taxing of smartphones without detachable batteries, favoring the business development of repair companies, oblige importers to organize the recovery and recycling of obsolete and non-repairable terminals, etc.

These principles set out the very **concept of "digital sobriety"** in the way it can be applied to the context of developing countries and in the way it can be promoted by international funding bodies.

The aim here is not to promulgate the de-intoxication of "artificial digital havens" such as have been named certain approaches in the developed countries, but to **maximize the efficiency (environmental as well as economic and social) of digital technology in development strategies.**

Conclusions

Before setting out the recommendations resulting from this work of analysis and modeling, we recall the main observations that we have been able to establish.

- **The current trend for digital overconsumption in the world is not sustainable with respect to the supply of energy and materials it requires.**

Digital transition **as it is implemented at present** results from a considerable expansion of the direct energy footprint of digital technologies, with an annual growth of from **9% to 10%** according to the different hypotheses.

This hyper-growth, occurring in spite of regular advances made up to now in the energy efficiency of digital devices and systems, is resulting in:

- The appropriation of a progressively disproportionate share of available electricity, increasing tension on the buildup of non-carbon production sources;
- The increase by half in 5 years of digital technology in GHG emissions (2.5% to 3.7% between 2013 and 2018) and a twofold increase of this ratio from now to 2025 (if data traffic continues to grow by 30% a year);
- Increasing demand for rare and critical metals of which many are essential for low carbon energy technologies, hence a risk of tension regarding supplies, exacerbated by the almost monopolistic position of China with respect to most of these metals.

- **The energy intensity of the digital industry in the world is increasing**

The comparison of the annual growth rate of 9% of digital energy consumption that we have highlighted, with the evolution of the sector's turnover (about 5%, (Arthur D. Little, 2017)) tends to show a **growth of its energy intensity of nearly 4% per year**, which runs counter to the improvement of the energy intensity of the world GDP, which is decreasing at present by 1.8% a year.

In other words, **consuming one euro of digital technology in 2018 induces direct and indirect energy consumption 37% higher than what it was in 2010**. This trend is the exact opposite of what is generally attributed to digital technology and runs counter to the objectives of energy and climatic decoupling set by the Paris Agreement.

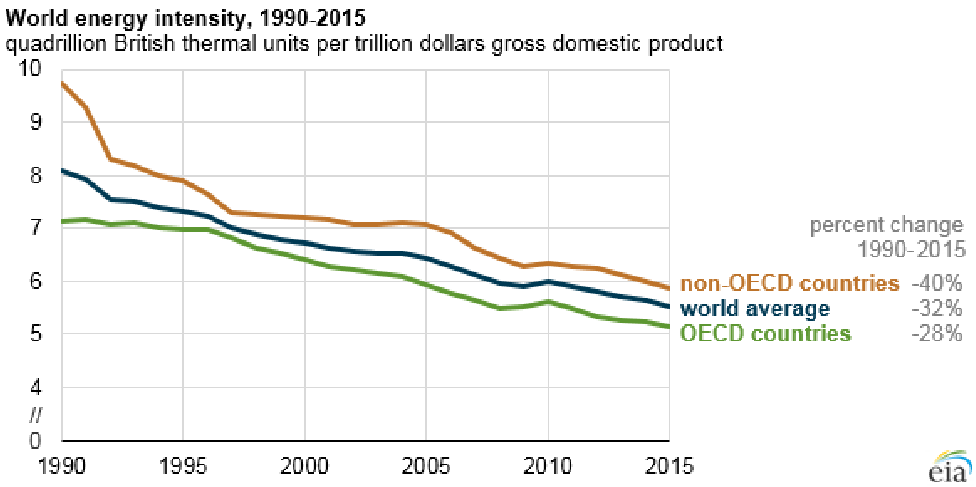


Figure 30: World energy intensity.
[Source: (EIA, 2016)*]*

- **Digital overconsumption does not have a perceivable impact on global economic performance**

Observation of the evolution of world GDP compared to that of digital expenses shows a **significant difference in growth in favor of digital technologies**. It has risen from 1.5 per cent in 2013 to 3 per cent since 2016 in the OECD zone, which coincides with the deployment of digital transition in these countries. However, whereas the growth of digital technologies has speeded up, the rate of economic growth has stagnated.

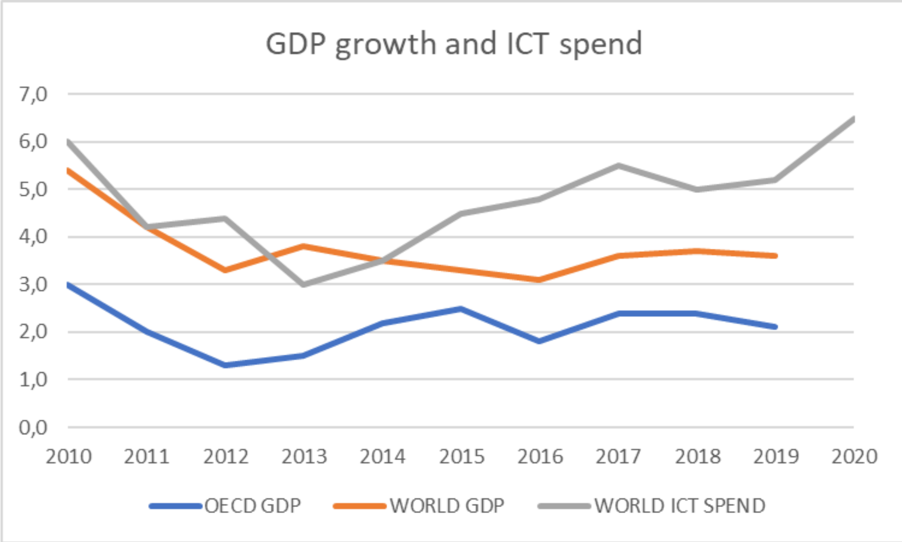


Figure 31: Comparative evolution of rates of growth of ICT expenses and GDP.
[Source: (IDC, IDC State of the Market 4Q17: IT Spending Review and Outlook, 2017c)*]*

As for the impact of digital technology on productivity, the general consensus reached regarding the concrete changes occurring during the period in which companies were becoming computerized (roughly 1990 to 2000), runs counter to the differences in opinion regarding the current phase of digital transition (since 2013) in the developed countries.

- **The environmental impact of digital transition becomes manageable if it is more sober**

The "Sobriety" scenario that we have studied permits containing the increase in digital energy consumption to 1.5% (instead of 9% today), i.e. a rate similar to the global trend (all sectors confounded).

It does not call into question the principle of digital transition: the volume of data transiting via data centers is increasing by 17% a year, the traffic on mobile networks by 24% a year, and the number of new terminals produced every year is stabilizing at the level of 2017, whereas the markets of the most developed countries are close to saturation. However, it is not enough to achieve a net reduction of the digital environmental footprint.

- **Current digital consumption is very polarized**

Digital consumption profiles differ remarkably: in 2018 and on average, an inhabitant of the United States owns nearly 10 connected digital peripheral devices and consumes about 140 Gigabytes of data a month, whereas an Indian owns 1 and consumes 2 Gigabytes.

Overconsumption is not generalized and is due to the developed countries and the United States in particular.

Regional split 2016	Population (millions)	Devices per capita	Traffic per capita (GB/mth)	GES (MtCO2e)	GES per capita (kgCO2e)
USA	322	7,8	97,0	331	**1027**
Western Europe	415	5,3	34,0	201	**486**
Japan	126	6,3	35,0	60	**474**
China	1374	2,5	12,0	400	**291**
Developing countries	3700	1,1	*1,5*	238	**64**
World	7500	2,3	13,0	**1630**	**217**

Table 17: Geographic distribution of digital consumption and its GHG emissions
[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Cisco, 2017b)*]*

The result of this situation is that the **digital carbon footprint of an American is 16 times larger than that of an inhabitant of a developing country** and 5 times larger than the world average, whereas this ratio is "only" 3.5 for all GHG emissions (OECD, 2018).

Given the observations recalled above, the simple application of a precautionary principle[47] should lead to at least calling into question the content of the digital transition as it is being implemented at present.

[47] "Principle according to which the absence of certitudes, in the light of current scientific and technical knowledge, should not hold back the adoption of effective and proportional measures aimed at preventing a risk in the areas of the environment, health and food", Glossaire de Vie Publique, on http://www.vie-publique.fr/th/glossaire/principe-precaution.html, consulted on 30/09/2018.

Although digital technology can serve to rethink uses and change modes of functioning and production in order to reduce GHGs, and even reduce energy consumption (smart grids, smart mobility and transport, environmental and urban monitoring, dematerialization, teleworking and videoconferences, smart buildings and eco-design tools), this can only occur if the rebound effects in these sectors can be efficiently managed.

However, **up to now, the rebound effects have proven themselves to be greater than the gains provided by technological innovation** (Magee & Devezas, 2017). For example, the environmental advantages of teleworking fall very short of what was intuitively predicted[48], or in any case when it is not combined with other changes of the social ecosystem.

It is therefore illusory to consider ***a priori*** that the global energy balance of a digital transition (of a service, company or country) is destined to be largely virtuous or even simply neutral.

So that digital transition *can* contribute to reducing the global energy consumption of a system, it is vital to change our consumption patterns and integrating digital technology in our projects, by applying the following recommendations.

1. Adopt digital sobriety as a principle of action

Reducing the energy and environmental footprint of digital technology requires returning to the individual and collective capacity to question the social and economic usefulness of our behaviors linked to purchasing and consuming digital objects and services, and to adapting them accordingly in order to avoid immoderation.

Limiting the renewal of terminals as much as possible, avoiding the multiplication of digital copies and segmenting our video uses are essential actions.

Sober digital behavior mainly consists in purchasing the least powerful devices possible, and changing them as seldom as possible, while reducing superfluous energy consuming uses (bulky attachments, videos, etc.).

2. Inform and spread awareness

Speeding up awareness of the environmental impacts of digital technology in companies and public organizations (via ISDs and DDDs), in the general public (labelling) and in the research community.

3. Mobilize the lever of public purchasing

Ensure that **public organizations embrace these impacts as a decision-making criterion** in their policies of purchasing and using digital devices, both in the developed and developing countries.

4. Allow companies and organizations to manage the environmental dimension of their digital transition

Ensure that companies and public organizations have the **references and tools that allow them to take into account the environmental impact of the digital component of the choices they consider**, at different levels of management: senior management when defining strategies, departmental managements when organizing operational activities, information system managements for managing digital infrastructures. Regarding the latter, **it is decisive that the demands for energy efficiency are clearly expressed to service providers**, especially regarding software development and cloud services. By taking the example of the DER, it is necessary to set up a **public database** so that the actors involved can analyze their environmental impacts.

[48] Cf report "Removing carbon from mobility in medium density areas", *The Shift Project*, 2017, on https://theshiftproject.org/article/publication-du-rapport-decarboner-la-mobilite-dans-les-zones-de-moyenne-densite-cest-possible/, consulted on 30/09/2018

5. Carry out a carbon balance of digital projects to facilitate their prioritization

Confronted by the pressure of supply (GAFAM, BATX) and the expected hyper-growth of different uses of digital technology, great attention must be given to **privileging digital projects intended for local economic, social (health, education) and cultural purposes in their evaluation of environmental impacts**. Particular attention must be given to the sectors of transport, energy and construction which, structurally, are those that emit the most GHGs. The developing countries, in which a large number of infrastructures remain to be created, will reap considerable benefits from such projects.

6. Improve consideration of the systemic dimensions of digital technology

Encourage consideration, through **interdisciplinary approaches**, of the direct and indirect environmental impacts of digital technology and its rebound effects in energy transition initiatives, especially in the sectors of energy, transport, habitat and agriculture-food; develop expertise around this approach to accelerate its implementation.

7. Work at the European scale and with international organizations

Given the global reach and economic power of the main actors of digital technology, aim at the implementation of these measures on a European scale. Promote them among organizations and institutions capable of playing a role of prescription in other regions of the world.

Given the complexity of the subject linked to its deeply systemic dimension and the speed at which digital technologies are evolving, we feel that it is pertinent to continue focusing on the interactions between digital transition and energy transition.

Several subjects have already been earmarked for works in 2019:

- Modeling and evaluating the environmental impact of SMART type projects (smart buildings, smart grids, etc.)
- Environmental conversion of a sectorial digital transition
- Impact of the IoT
- Resilience and digital technology
- Digital sobriety and the psycho-societal context
- Energy and digital magnitudes: charts for user companies
- Etc.

Appendices

a. Appendix 1: Energy consumption and digital technology 2013-2025

Expected updated								
ENERGY CONSUMPTION (in TWh)	**2013**	**2014**	**2015**	**2016**	**2017**	**2020**	**2023**	**2025**
CONSUMER DEVICES	380	426	457	531	575	744	846	908
NETWORKS	435	433	463	471	478	546	676	1007
DATA CENTERS	323	322	400	498	593	894	1242	1918
TOTAL USE	1137	1181	1320	1500	1646	2183	2764	3834
U: % TOTAL ELECTRICITY CONSUMPTION	**5,8%**	**5,9%**	**6,5%**	**7,2%**	**7,6%**	**9,2%**	**10,6%**	**13,7%**
TOTAL PRODUCTION	889	962	1053	1166	1344	1713	2097	2492
P: % TOTAL ELECTRICITY CONSUMPTION	**4,6%**	**4,8%**	**5,2%**	**5,6%**	**6,2%**	**7,2%**	**8,0%**	**8,9%**
TOTAL USE AND PRODUCTION	2026	2142	2373	2666	2990	3896	4861	6326
% TOTAL ELECTRICITY CONSUMPTION	**10,4%**	**10,8%**	**11,7%**	**12,8%**	**13,9%**	**16,4%**	**18,6%**	**22,6%**
GHG FROM USE (Mt)	705	720	805	915	988	1288	1631	2224
GHG FROM PRODUCTION (Mt)	551	587	642	711	806	1011	1237	1445
GHG TOTAL	1256	1307	1448	1626	1794	2299	2868	3669
% TOTAL GHG EMISSIONS	**2,6%**	**2,6%**	**2,9%**	**3,2%**	**3,4%**	**4,3%**	**5,6%**	**7,6%**
% FINAL ENERGY CONSUMPTION	**1,9%**	**2,0%**	**2,2%**	**2,4%**	**2,7%**	**3,4%**	**4,1%**	**5,2%**

[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)]

Higher growth higher EE								
ENERGY CONSUMPTION (in TWh)	**2013**	**2014**	**2015**	**2016**	**2017**	**2020**	**2023**	**2025**
CONSUMER DEVICES	380	426	457	531	575	744	846	908
NETWORKS	435	433	463	471	478	576	744	1166
DATA CENTERS	323	322	400	503	559	651	802	1236
TOTAL USE	1137	1181	1320	1506	1613	1971	2393	3310
U: % TOTAL ELECTRICITY CONSUMPTION	**5,8%**	**5,9%**	**6,5%**	**7,2%**	**7,5%**	**8,3%**	**9,1%**	**11,8%**
TOTAL PRODUCTION	889	962	1053	1167	1338	1682	2041	2413
P: % TOTAL ELECTRICITY CONSUMPTION	**4,6%**	**4,8%**	**5,2%**	**5,6%**	**6,2%**	**7,1%**	**7,8%**	**8,6%**
TOTAL USE AND PRODUCTION	2026	2142	2373	2672	2951	3652	4434	5723
% TOTAL ELECTRICITY CONSUMPTION	**10,4%**	**10,8%**	**11,7%**	**12,8%**	**13,7%**	**15,4%**	**16,9%**	**20,5%**
GHG FROM USE (Mt)	705	720	805	918	968	1163	1412	1920
GHG FROM PRODUCTION (Mt)	551	587	642	712	803	992	1204	1400
GHG TOTAL	1256	1307	1448	1630	1771	2155	2616	3320
% TOTAL GHG EMISSIONS	**2,6%**	**2,6%**	**2,9%**	**3,2%**	**3,4%**	**4,0%**	**5,1%**	**6,9%**
% FINAL ENERGY CONSUMPTION	**1,9%**	**2,0%**	**2,2%**	**2,4%**	**2,7%**	**3,2%**	**3,8%**	**4,7%**

[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)

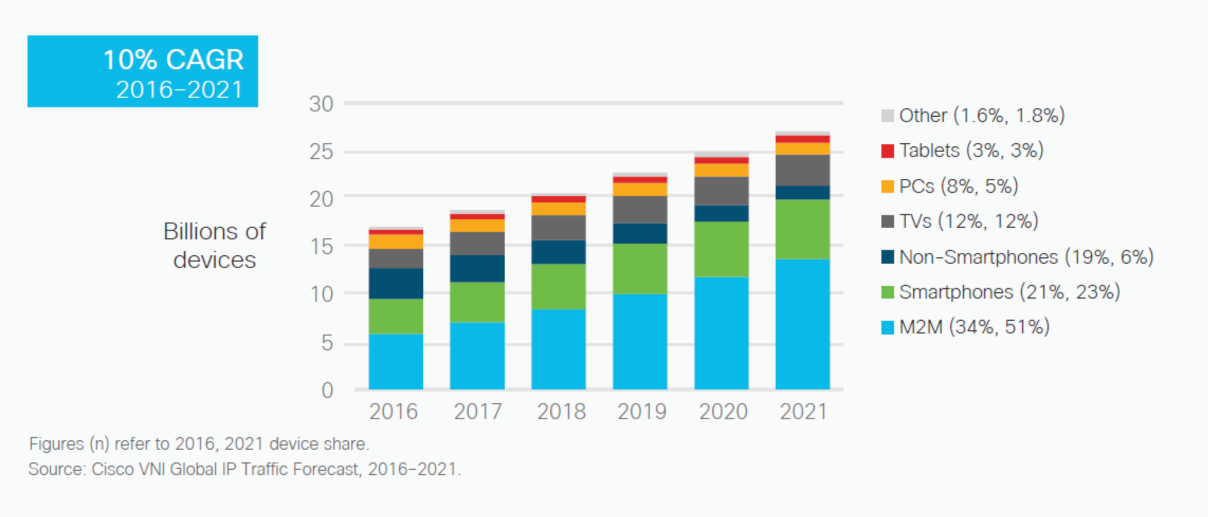
Higher growth peaked EE								
ENERGY CONSUMPTION (in TWh)	**2013**	**2014**	**2015**	**2016**	**2017**	**2020**	**2023**	**2025**
CONSUMER DEVICES	380	426	457	531	575	744	846	908
NETWORKS	435	433	463	471	478	576	880	1562
DATA CENTERS	323	322	400	503	559	651	1014	2040
TOTAL USE	1137	1181	1320	1506	1613	1971	2740	4511
U: % TOTAL ELECTRICITY CONSUMPTION	**5,8%**	**5,9%**	**6,5%**	**7,2%**	**7,5%**	**8,3%**	**10,5%**	**16,1%**
TOTAL PRODUCTION	889	962	1053	1167	1338	1692	2160	2759
P: % TOTAL ELECTRICITY CONSUMPTION	**4,6%**	**4,8%**	**5,2%**	**5,6%**	**6,2%**	**7,1%**	**8,2%**	**9,9%**
TOTAL USE AND PRODUCTION	2026	2142	2373	2672	2951	3662	4901	7270
% TOTAL ELECTRICITY CONSUMPTION	**10,4%**	**10,8%**	**11,7%**	**12,8%**	**13,7%**	**15,4%**	**18,7%**	**26,0%**
GHG FROM USE (Mt)	705	720	805	918	968	1163	1617	2616
GHG FROM PRODUCTION (Mt)	551	587	642	712	803	998	1275	1600
GHG TOTAL	1256	1307	1448	1630	1771	2161	2891	4217
% TOTAL GHG EMISSIONS	**2,6%**	**2,6%**	**2,9%**	**3,2%**	**3,4%**	**4,0%**	**5,7%**	**8,8%**
% FINAL ENERGY CONSUMPTION	**1,9%**	**2,0%**	**2,2%**	**2,4%**	**2,7%**	**3,2%**	**4,1%**	**6,0%**

[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)]

Sobriety								
ENERGY CONSUMPTION (in TWh)	**2013**	**2014**	**2015**	**2016**	**2017**	**2020**	**2023**	**2025**
CONSUMER DEVICES	380	426	457	531	575	744	846	908
NETWORKS	435	433	463	471	478	576	579	582
DATA CENTERS	323	322	400	503	559	651	753	761
TOTAL USE	1137	1181	1320	1506	1613	1971	2178	2251
U: % TOTAL ELECTRICITY CONSUMPTION	**5,8%**	**5,9%**	**6,5%**	**7,2%**	**7,5%**	**8,3%**	**8,3%**	**8,1%**
TOTAL PRODUCTION	889	962	1053	1167	1338	1682	1484	1460
P: % TOTAL ELECTRICITY CONSUMPTION	**4,6%**	**4,8%**	**5,2%**	**5,6%**	**6,2%**	**7,1%**	**5,7%**	**5,2%**
TOTAL USE AND PRODUCTION	2026	2142	2373	2672	2951	3652	3662	3710
% TOTAL ELECTRICITY CONSUMPTION	**10,4%**	**10,8%**	**11,7%**	**12,8%**	**13,7%**	**15,4%**	**14,0%**	**13,3%**
GHG FROM USE (Mt)	705	720	805	918	968	1163	1285	1305
GHG FROM PRODUCTION (Mt)	551	587	642	712	803	992	875	847
GHG TOTAL	1256	1307	1448	1630	1771	2155	2160	2152
% TOTAL GHG EMISSIONS	**2,6%**	**2,6%**	**2,9%**	**3,2%**	**3,4%**	**4,0%**	**4,2%**	**4,5%**
% FINAL ENERGY CONSUMPTION	**1,9%**	**2,0%**	**2,2%**	**2,4%**	**2,7%**	**3,2%**	**3,1%**	**3,1%**

[Source: [Lean ICT Materials] Forecast Model. Produced by The Shift Project from data published by (Andrae & Edler, 2015)]

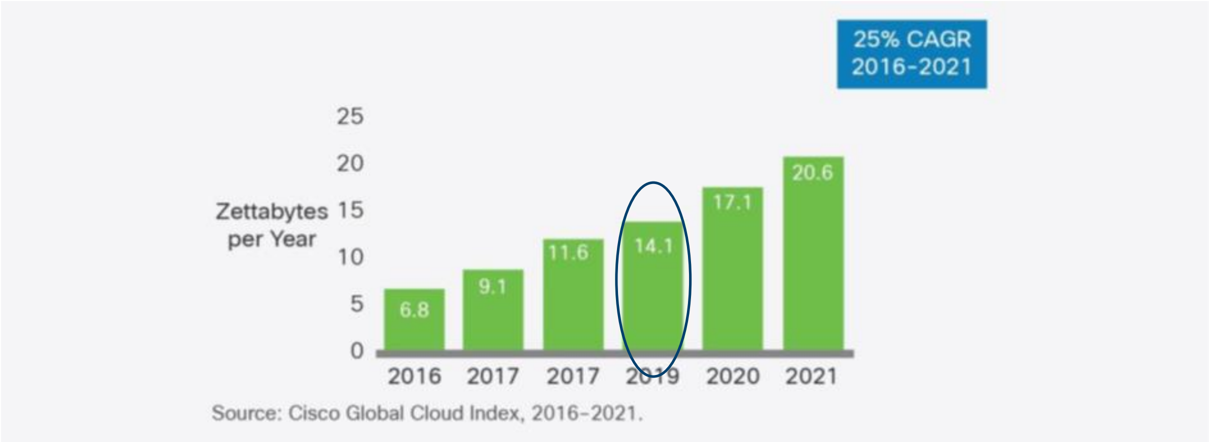
b. Appendix 2: Evolution of the number of connected terminals



[Source: (Cisco, 2017a)]

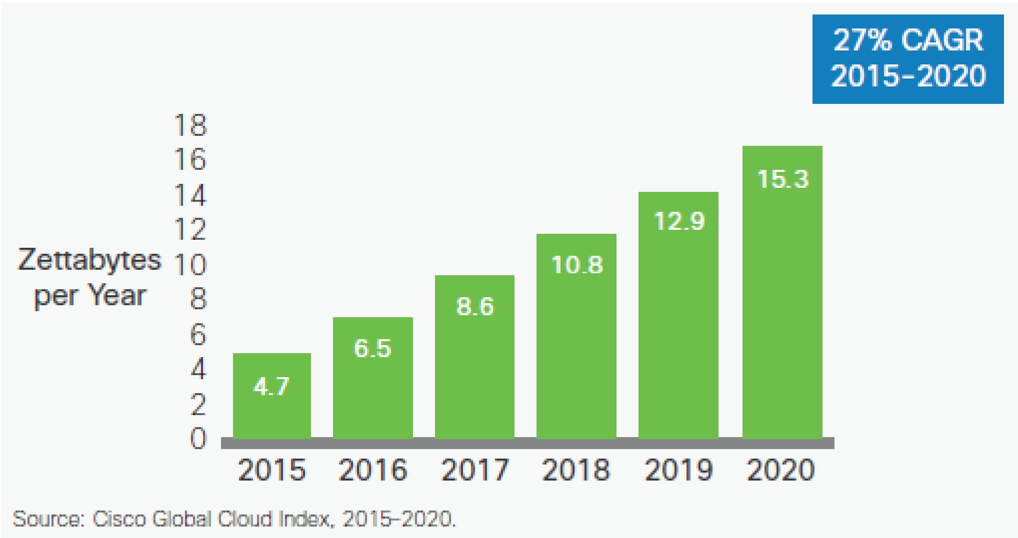
c. Appendix 3: Evolution of data center traffic and networks

1. Forecasts in 2017



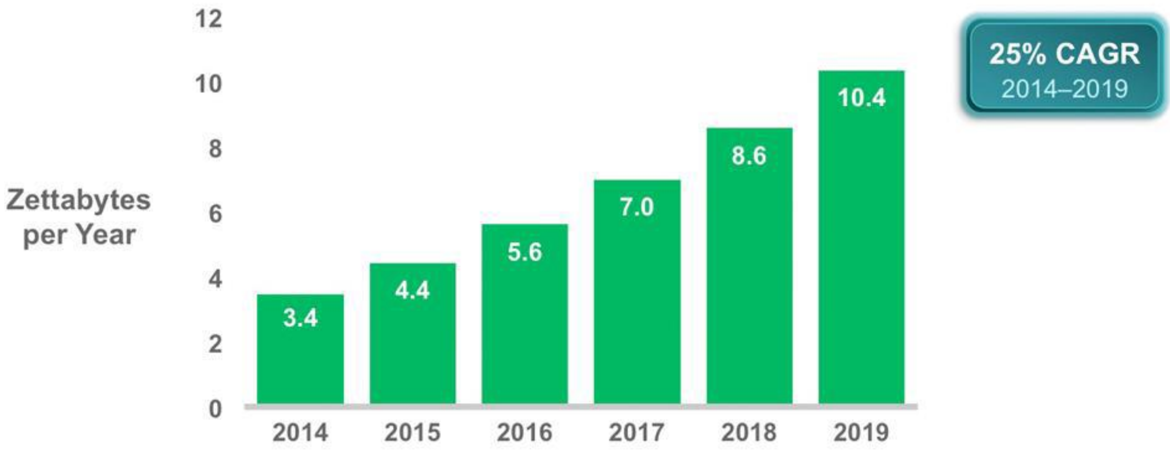
[Source: (Cisco, Visual Networking Index: Global - 2021 Forecast Highlights, 2017)]

2. Forecasts in 2016



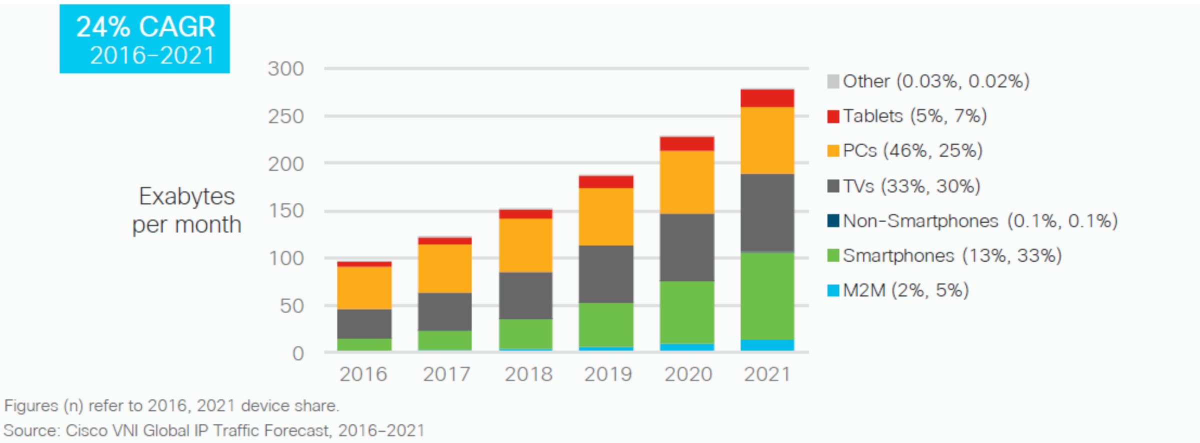
[Source: (Cisco, 2016a)]

3. Forecasts in 2015



[Source: (Cisco, 2015)]

4. IP traffic on networks



[Source: (Cisco, 2017a)]

d. Appendix 4: Methodological note of the "Digital Environmental Repository"

General approach

The purpose of the Digital Environmental Repository (DER) is to describe, in the form of characteristic magnitudes and ratios, the environmental footprint of the digital ecosystem in terms of equipment and uses.

Thus, a selection of digital devices and uses has been chosen to represent and illustrate the environmental impact caused by the components of digital technology.The quantification of the environmental impacts performed in the framework of the Digital Ecological Repository is intended to produce results that are pertinent and representative of the entire digital ecosystem and not only certain specific cases. Without pretending to be exhaustive, the aim of this work is therefore to build a preliminary database to be refined collectively.

To achieve this, these results are presented in the form of averages and magnitudes resulting from crossing data of different origins (scientific articles, government reports, works done by independent research bodies, manufacturers' documents, etc.).

The studies and resources used were selected from after 2013 as much as possible to ensure the relevance of the data extracted given the pace at which the digital sector is evolving.

The choices and hypotheses made when designing this repository are set out as exhaustively and transparently as possible in the rest of this document, to allow criticism, evaluation and discussion.

Definitions adopted

1. Definition of digital elements

There are two types of *digital element*: **digital devices and actions.** They are aspects of "Digital Technology" chosen to quantify their environmental impacts.

Digital devices are products whose operation and associated services are based on digital technologies and networks. The devices selected in the DER are the following:

- The smartphone;
- The laptop computer;
- The data center;
- The connected TV, or Smart TV;
- The Residential router.

These devices were chosen to cover the activities of an average digital technology user in the European Union.

Digital actions are activities performed via a **device** and involve the use of the network. The actions selected for the DER are the following:

- Sending an email;
- Watching a video on line.

These digital actions were chosen for their illustrative value, in order to represent certain common uses of an average use of digital technology in the European Union whose impact is quantifiable in terms of magnitude.

Contrary to the devices, for which the aim is to constitute a genuine quantitative repository, the quantification performed of digital actions is performed simply to give examples of the material energy content of certain actions called "virtual".

2. Definition of life phases

In the following we present the definitions chosen to describe the lifecycle of digital elements studied in the first deliverable, the "Digital Ecological Repository".

a. Definition of the "production" phase

The production phase concerns the digital devices. It is defined as the phase prior to implementation by the user. It includes:

- The raw material extraction phase;
- The production of the components;
- The assembly of the devices.

This study does not include environmental impacts linked to the production of network infrastructures.

b. Definition of the "utilization" phase

The utilization phase concerns the digital devices and the digital actions.

For the devices, it is defined as the period extending throughout the lifetime of the device from its first use, without taking its end of life phase into account.

For the digital actions, it is defined as the period of performing the action only. The contributions of the devices used are considered only through the phase of their utilization and are limited to the time of using the devices assigned to perform the action.

c. "End of life" phase

The "end of life" phase is outside the scope of this study due to the lack of reliable data on a large scale.

Hypotheses and methodologies

1. Phase de production

In the following the hypotheses chosen for building the *"Production Phase"* part of the first deliverable, the "Digital Environmental Repository", are presented.

a. Energy impacts – Production phase

The energy consumption associated with the production phase is evaluated on the basis of *primary energy* consumption. The quantification of the share of electricity consumption of total primary energy consumption is considered as not being sufficiently reliable for inclusion in our results.

b. GHG emissions – Production phase

The GHG emissions characterize the quantity of CO_2 equivalent (in $kgCO_2eq$) emitted during production activities (extraction of raw materials, production and assembly of components).

c. Metals – Production phase

The impacts relating to metal resources represent the weight of metals (in g) contained in the device considered.

The metals chosen for quantification in our Repository were selected according to main criteria: their criticality and their level of involvement in digital technologies.

Their criticality, evaluated through the works of the European Commission (Oakdene Hollins Research & Consulting, Fraunhofer ISI, 2013), is characterized on the basis of their economic importance and the risks incurred for their supply.

Their level of involvement in digital technologies, evaluated on the basis of previous works by the members of the Working Group (Bihouix P. , 2015) as well as scientific publications (Institut Mines-Télécom, 2016), is characterized through the uses made of these technologies (essential components, wiring, etc.) and through the share that digital technologies represent in the total world demand for these metals.

Thus, the list drawn up is the following:

- Gallium
- Indium
- Tantalum
- Copper
- Cobalt
- Palladium

The aim of this list is not therefore to completely and exhaustively quantify the metal content of the devices: rather the goal is to produce a preliminary set of magnitudes that are relevant in the light of current and future challenges regarding the mineral resources necessary for digital technologies.

d. Ore extracted volume – production phase

The impact of *"Ore Extracted Volume"* represents the volume of ore moved (in m^3) needed to extract the metals used to produce digital devices.

It is calculated only for metals belonging to the list set out above (cf. c. Metals – production phase). For each of them, the volume of the ore required for producing the device is calculated on the basis of the weight of metal contained in the device and the concentration of the metal in the ore.

Since there is no quantitative measure of biodiversity erosion by mining activities currently available, the indicator "Ore Extracted Volume" permits manifesting an initial degree of impact on biodiversity and soil erosion, through a preliminary quantitative representation of the area harmed by the extraction process.

e. Devices – Production phase

Smartphone

The impacts presented are given for an average smartphone, corresponding to a standard smartphone supplied by Lifecycle Analysis (LCA) and the *Declaration of Materials* used in the framework of the works of a company in the sector on the environmental impact of devices.

The smartphone considered is a 2014 model, equipped with an LCD screen with a diagonal dimension of 4.5 inches and a NAND memory of 32 Gigabytes.

Laptop computer

The impacts presented are given for an average laptop computer, corresponding to a standard laptop supplied by the associated *EIME* software and the *Bill of Materials* used in the framework of the works of a company in the sector on the environmental impact of devices.

The computer considered is a T3 model of 2013, equipped with an LCD screen with a diagonal dimension of 14 inches and an SSD memory of 256 Gigabytes.

Server (Data Center)

The environmental impact of the data center is characterized through that of servers to obtain a pertinent quantification, overcoming in particular the very high uncertainties resulting from the diversity of data center structures (cooling systems, maintenance, types of redundancy, etc.).

The impacts presented are given for an average server, resulting from a combination of modular analyses performed via EcoInvent and the Fujitsu PRIMERGY TX 300 S5 server (cf. f. Sources – Production phase , below).

Connected TV

The impacts presented are given for a connected TV corresponding to a standard model supplied by the *Environmental Product Declaration* from the manufacturer Samsung on the basis of which the impact calculations were performed in the framework of the works of a company in the sector on the environmental impact of devices.

The TV considered is an LCD TV equipped with a *blacklight LED* screen with a diagonal dimension of 55 inches[49].

f. Sources – Production phase

In order to use the data resulting from an approach whose methods are known to the working group, the impacts of the production phase of personal devices (smartphone, laptop PC and connected TV) were obtained from the works performed by the members of the working group in the framework of their professional activity in a company operating in the sector. Since traditional sources (scientific articles, private studies) do not give sufficient access to methodological details and the hypotheses used, the decision was taken not to use them.

An exception was made for the metal content of the smartphone, for which the results of our main source were crossed with those of a publication by Greenpeace on the basis of the works of Oeko-Institut (Greenpeace, 2017).

The sources used to build the indicator "Ore Extracted Volume" are the metal concentration data from scientific works (Vidal, 2018) and technical publications (Gérôme J-A., 2017) (Polak, 2009).

The data on the impacts of producing a data center server come from a comparative study performed by the ADEME in 2012 (ADEME, 2012).

[49] The environmental impacts of an LCD are proportional, on first analysis, to the surface of the screen.

2. Utilization phase

The following paragraphs present the hypotheses chosen to build the *"Run Phase"* section of the first deliverable, the "Digital Environmental Repository" spreadsheet.

a. Energy impacts – Utilization phase

The energy consumption associated with the utilization phase is evaluated via electricity consumption, which is more accurate and pertinent for this phase.

b. GHG emissions – Utilization phase

GHG emissions are calculated on the basis of electricity consumption, by applying a carbon intensity factor (in kgCO_2eq/kWh) to this consumption.

The carbon intensity factors are calculated for the electricity mixes of four regions: the European Union, France, USA and China. They are calculated on the basis of works performed by the International Energy Agency (International Energy Agency (IEA), 2016), the European Environment Agency (EEA, 2016) and a review of the world energy consumption performed by the company British Petroleum (BP, 2017).

c. Devices – Utilization phase

Smartphone

The impacts presented are given for an average smartphone, corresponding to an average established for several brands (the main manufacturers in terms of market share) and medium range models[50].

The electricity consumption of electricity grid infrastructures generated by smartphone activity is not taken into account. The electricity consumption presented here is only the direct consumption of the device.

Laptop computer

The impacts presented are given for an average laptop computer, corresponding to an average established for several brands (the main manufacturers in terms of market share) and medium range models [7].

The electricity consumption of electricity grid infrastructures generated by the devices is not taken into account. The electricity consumption presented here is only the direct consumption of the equipment.

Data centers

The impacts presented are given for an average data center, characterized by its surface area and the total power capacity of its installations (in MW):

- Surface area of the average data center: 1,000 m²;
- Power of an average data center: 1 MW;
- PUE (Power Usage Effectiveness): 2.

Here the qualification "average" designates a data center large enough to belong to major infrastructures (presence of cooling systems, redundancy mechanisms, etc.) but without belonging to the class of data center classified as *"hyperscale"*.

These characteristics were chosen by consultation with the experts of the working group and the Services Group of CNRS EcoInfo.

It should be recalled that the impacts calculated here represent the electricity consumption of the entire infrastructure though only during its utilization phase: the construction and destruction of buildings are not taken into account here.

Connected TV

The impacts presented are given for an average connected, corresponding to an average established for several brands (the main manufacturers in terms of market share) and medium range models (50 to 60-inch screens).

Residential router

The impacts presented are given for an average router, whose consumption is calculated on the basis of data resulting from the works of the Working Group (in EcoInfo and in a company operating in the sector), crossed with different secondary sources of comparative studies[51].

Residential router consumption is calculated for the network uses linked to the IP router: uses linked to "TV Box" functions are not included in this calculation.

[50] Detailed in "[Lean ICT Materials] REN", tab *"kWh Run (Devices)"*. Produced by *The Shift Project*.
[51] Detailed in "[Lean ICT Materials] Residential Router Electricity Consumption". Produced by *The Shift Project*.

To determine the annual consumption of a router, an average equipment power (in W) is extracted from the data collected for several internet providers on the basis of the works of the Services Group of CNRS EcoInfo, comparative consumer studies and data from the experts of the Working Group gleaned from the works of a company in the sector[52]. This average power is then used to calculate an annual consumption (in kWh/year) on the basis of the user profile chosen[53]. The order of magnitude is then conserved for reporting in the Repository[54].

Utilization profiles

The impacts are calculated for standard annual utilization profiles resulting from government studies and studies by private consultants:

- **Smartphone:** 2.5 h/day. Profile calculated on the basis of statistical studies on the current use at the world level according to age class (Kantar TNS, 2015), rounded to an average use by weighting the results by the different proportions of age classes in the world population;
- **Laptop computer:** 8 h/day. Average profile considered for professional use[55], taken from studies performed by the American government label *"Energy Star"* (Energy Star, 2014);
- **Connected TV:** 5 h/day. Average profile resulting from profiles used by the American government label *"Energy Star"* (Samsung , 2017)[56] and works presented in the scientific article cited (Hischier, 2014);
- **Residential router:** permanently ON, i.e. constant consumption 24h/24 corresponding to the active mode of the router. This profile is consistent with the uses observed.

d. Digital actions – Utilization phase

Definition of actions

The action "*Send an email"* is characterized as follows:

- Utilization time of associated device: 3 minutes;
- Size of data transferred (including attachment): 1 Mb.

The action *"Watch a video film online"* is characterized as follows:

- Utilization time of associated device: 10 minutes;
- Size of data transferred (high quality video 1,080p): 170 Mb.

Calculation methodology: "1 byte" model[57]

The impacts are calculated for a unit performance of the action considered, based on the electric energy needed for this performance in kWh.

The approach chosen consists in evaluating the average energy impact (electric energy) of one byte[58] of data via a model, the "1byte" model, built by the working group, then calculating the impact of the action with respect to the size of the data involved to perform it.

The quantification of this unit impact is done in *kWh/byte*. Three contributions are considered:

- The electricity consumption associated with using the terminal on which the action is performed;
- The electricity consumption generated by the activity of the data centers involved in transferring the data;
- The electricity consumption generated by the activity of the other network infrastructures during the transfer of the data.

The contribution of the terminal is calculated for two cases: the performance of an action on a smartphone and an action on a laptop computer. The consumption due to using the terminal is calculated on the basis of the hourly consumption of the terminal[59] and the duration of use associated with the action[60].

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[52] Detailed in "[Lean ICT Materials] Residential Router Electricity Consumption". Produced by *The Shift Project*.
[53] cf. following paragraph "Utilization Profiles"
[54] cf. "[Lean ICT Materials] REN", tab *"kWh Run (Devices)"*. Produced by *The Shift Project*.
[55] This choice was made to ensure consistency with the target actors of "Company levers" (cf. IV. Digital sobriety in the company: examples of action levers): companies using digital technology.
[56] [15] Samsung (2017). *Energy Guide of the "55" Class MU7000 4K UHD TV".* EnergyGuide Label.
[57] Available in "[Lean ICT Materials] 1byte Model". Produced by *The Shift Project*.
[58] 1 byte = 8 bits
[59] Hourly consumption is calculated on the basis of annual consumption and utilization profile. Detailed in "[Lean ICT Materials] 1byte Mode". Produced by *The Shift Project.*
[60] cf. "Definition of actions" above.

The contribution associated with the activity of the data centers involved is calculated on the basis of macroscopic data resulting from preliminary work done by the "Lean ICT" work group[61]: a ratio is calculated between the quantity of data transferred at the macroscopic scale by data centers with the electricity consumption associated with the utilization of these data centers[62].

The contribution associated with the activity of other network infrastructures is calculated for several cases, corresponding to different types of network considered: the wired fixed network (FAN), the fixed WIFI network (FAN WIFI), the smartphone network. The electricity consumption is calculated on the basis of macroscopic data resulting from a preliminary study by the "Lean ICT" work group[26], also according to the same methodology as for the contribution of the data centers.

These results were then reviewed critically by experts and by comparison, with macroscopic orders of magnitude[63] and with a study carried out by the *Centre for Energy-Efficient Telecommunications* (CEET), an Australian research institute (CEET, 2013), that supplies quantitative values on the scale of a *byte* of data.

The consumption presented in the DER for each action is the result expressed by order of magnitude, determined on the basis of the non-weighted arithmetical average of the different cases set out above (carrying out an action by smartphone or laptop computer and the type of network used).

e. Sources – Utilization phase

Devices

The sources used to determine the electricity consumption of devices come from crossing three types of study[64]:

- Lifecycle analyses performed by device distribution companies;
- Comparative studies performed by public bodies and independent research centers;
- Research articles from scientific journals.

The GHG emissions are calculated on the basis of emission factors stemming from the works of the European Environment Agency and the International Energy Agency[65].

The calculation of the annual energy consumption of the data center is calculated on the basis of a study in a scientific publication (Shehabi, A. et al., 2016), whose results were adapted to our average data center. These results were then compared with orders of magnitude supplied by the experts of the Working Group and with a field study carried out by a private company (ENR'CERT, 2016).

Digital actions

The sources used to determine electricity consumptions with the "1byte" model are a combination of several types of resource:

- Results from the productions of the "Lean ICT"[66] project,
- Studies of governmental bodies, public research centers and private study centers[67].

[61] Detailed in "[Lean ICT Materials] Forecast Model"
[62] Detailed in "[Lean ICT Materials] 1 byte Model"
[63] By considering ratios between the quantity of data exchanged in the world the associated electricity consumption, for example in (Bihouix P. M., 2016)
[64] Detailed in "[Lean ICT Materials] REN", tab "Sources". Produced by *The Shift Project*.
[65] cf. (International Energy Agency (IEA), 2016b) (*The Shift Project*, 2017b) (EEA, 2016) (BP, 2017) (Kantar TNS, 2015)
[66] "[Lean ICT Materials] REN". Produced by *The Shift Project*; "[Lean ICT Materials] Forecast Model"
[67] cf. (CEET, 2013) (Shehabi, A. et al., 2016)

e. Appendix 5: Methodological note of "Corporate levers"

Hypotheses and general methodology

1. Hypotheses

a. Targets of recommendations and levers

The purpose of the recommendations formulated in the framework of the "Lean ICT" is to propose examples of operational measures that can be implemented by companies that use digital technology to reduce the environmental impacts of their digital ecosystems.

By "company using digital technology", we exclude the activities of producing devices and services. The recommendations were therefore formulated by considering companies solely from the angle of "user of devices and services provided to them", in order to be as adaptable as possible regarding the different cases.

The term "companies" is used, but these recommendations are compatible with wider applications, most of them can be applied or easily adapted to any type of "organization": public institutions, private bodies, hospitals, etc.

b. Geographical region

The purpose of the levers is to illustrate the possible evolutions of the environmental impacts of digital technology when implemented in companies subject to European Union regulations.

c. Time horizon

The study of the lever effects is performed in a real situation: no hypothesis is made regarding the change of the context or the transitory periods. The objective is to quantify the difference between the real situation at present and a hypothetical situation where, all things being equal elsewhere, the lever is triggered.

2. Methodology

a. Objectives

The "Company levers" offer operational solutions aimed at reducing the environmental impact of the digital activities of a company.

The first objective is to propose examples of solutions whose effect can be quantified and to perform the calculation, in order to illustrate the impact of an approach of sobriety when it is rigorously implemented in a company.

The second is to give examples of methodologies of quantifying the effects of a sobriety measure. This type of methodology can be reused by the company and permits predicting a magnitude for the effect of a decision on the annual environmental impact of the company's digital activities.

The calculations and results presented in this deliverable therefore have an illustrative and non-exhaustive value: obviously, their validity is linked to the framework of the hypotheses chosen though the orders of magnitude and trends that emerge allow showing that decision-making bodies can quickly take into account the quantitative importance of a measure of digital sobriety for a given situation and context.

b. Methodology

To quantify the effect of each lever, the following steps were performed:

- The levers were selected by judging their ease of operational implementation and the possibilities of quantifying their effects.
- An "indicator" was determined for each of the levers chosen: it expresses the dimension of the digital ecosystem in which it acts (for example: the lifetime of a terminal).
- The calculation hypotheses have been set for each lever: the initial situation, called "current", is defined without a lever, followed by the situation with a lever. These hypotheses are aimed at giving a framework to the calculation that is consistent with the real situations of companies (examples of hypotheses: the size of electronic documents transferred, smartphone utilization profile, etc.).
- The calculations are then built, by using in particular data developed in the upstream phases of the project to quantify the reduction in terms of the GHG emissions (in $kgCO_2eq$) of the emission item concerned.

Since GHG emissions are an indicator of an environmental impact common to the production and utilization phases in our approach[68], they have been chosen to characterize the environmental impact in this exercise – as this comparison is necessary to formulate the calculations. In order to contextualize these results in the approaches based on Carbon Balance type methodologies, the calculations are performed for the annual impact of the company.

The effect of levers is evaluated relatively in comparison to the impact of the item of emission considered: the calculation (in %) concerns the relative reduction that the emissions would undergo if we start from the initial situation and pass to the situation with the lever, all things being equal elsewhere.

The effect of each lever is therefore characterized as the relative reduction of annual GHG emissions of the item of emission concerned by its activation.

Hypotheses and methodology of levers

1. Levers no.1 & no.2: Increasing the lifetimes of the company's devices

a. Description of levers

Indicator

The indicator associated with these levers is the lifetime of the devices.

Aim of the levers

Levers 1 and 2 are based on the same methodology, applied to two devices:

- Laptop computer (lever 1),
- Smartphone (lever 2).

Although the same methodology is used in both cases, the separation of these measures into two distinct levers is justified by the differences between their operational application (practical implications, security and confidentiality problems, device management, etc.).

The lever recommends increasing the lifetime of the devices to lower the pressure of the production phase on their annual impact.

b. Hypotheses

1. Initial situation – current lifetime:
   - Laptop computer: 3 years;
   - Smartphone: 2.5 years.

2. Situation with lever – longer lifetime:
   - Laptop computer: 5 years;
   - Smartphone: 3.5 years.

c. Quantification methodology

The following steps were performed to quantify the effect of this lever on the annual impact:

- The annual impact of the device (in $kgCO_2eq$/year) was calculated with the current lifetime (initial situation). It corresponds to the distribution of the impact of production on the whole lifetime, added to the emissions linked to the annual consumption of the device in the utilization phase.
- The annual impact of the device (in $kgCO_2eq$/year) was then calculated in the same way with the lengthened lifetime (situation with lever).
- The relative reduction (in %) of the annual impact of the device when activating the lever is deducted from the two previous calculations.
- This reduction gives us the reduction of the annual impact (in %) of all the devices directly, since the total environmental impact of all the devices is directly proportional to the impact of a terminal – via the number of terminals.

[68] cf. Appendix 4: Methodological note of the "Digital Environmental Repository"

d. Sources

The emissions associated with the production and utilization phases come from the first deliverable produced by the working group in the framework of this report: the Digital Environmental Repository (DER)[69].

The lifetimes are part of the calculation hypotheses. They were chosen on the strength of the opinions of the experts of the work group in order to ensure consistency with the reality of situations in companies.

2. Lever no.3: Generalizing the "pro-personal" offer for company smartphones

a. Description of lever

Indicator

The indicator chosen is the number of professional smartphones.

Aim of the lever

The lever proposes to increase the share of smartphones assigned with the "pro-personal" offer of 20% to 70% in the number of professional smartphones.

b. Hypotheses

1. Initial situation – current share of the number of professional smartphones assigned with the "pro-personal" offer: 20%.
2. Situation with lever – increased share of number of professional smartphones composed of smartphones assigned with the "pro-personal" offer: 70%.
3. Daily utilization profiles:
    - Utilization profile for personal use ("personal" profile): 2.5 h/d
    - Utilization profiles for professional use ("pro" profile): 2 h/d
4. The total of the two types of use ("pro" and "personal") on the same device is not considered as having an impact on the device's lifetime (Quechoisir, 2015).
5. It is considered that the utilization profiles are added together, without an effect of substitution between personal and professional uses.

c. Quantification methodology

The following steps were performed to quantify the effect of this lever on the annual impact:

- The annual utilization profiles were calculated on the basis of daily utilization profiles and the number of days of smartphone utilization in the year:
    - 365.25 days a year (every day) for personal use;
    - 227 days a year (average number of days worked in France for a year of 52 weeks of 5 days, 5 weeks paid holidays and 8 national holidays in the week on average[70]) for professional use.
- The annual "pro-personal" utilization profile was calculated as the sum of annual "pro" and "personal" utilization profiles[71].
- The annual impact of the smartphone (in $kgCO_2eq$/year) was calculated with the annual "pro" utilization profile (initial situation). It corresponds to the distribution of the impact of production on the whole lifetime, to which is added the annual consumption of the device in the utilization phase.
- This annual consumption in utilization phase was calculated on the basis of the hourly consumption of the smartphone[72] and the annual utilization profile.
- The annual impact of the smartphone (in $kgCO_2eq$/year) was then calculated in the same way with the "pro-personal" utilization profile (situation with lever).
- The share attributed to "pro" uses in the annual impact of the "pro-personal" profile was calculated on the basis of the hourly ratio (share of the "pro-personal" profile attributed to professional use): this allowed calculating the impact of exclusively professional use of the smartphone used in the "pro-personal" profile: $GHG_{pro\text{-}personal}$.
- The relative reduction (in %) of the annual impact of the number of professional smartphones was obtained by comparing the impact in the initial situation with that of the situation with the lever.

[69] Available in "[Lean ICT Materials] REN". Produced by *The Shift Project*.

[70] Détaillé dans "[Lean ICT Materials] QuantiLev", tab *"Lev 3"*. Produced by *The Shift Project*.

[71] According to hypothesis 5.

[72] Detailed in "[Lean ICT Materials] QuantiLev", tab "*Lev 3*". Produced by *The Shift Project*.

- Each of these two impacts is equal to the sum of two contributions:
  - $GHG_{all} = (1 - f_{pro-personal}) * GHG_{pro} + f_{pro-personal} * GHG_{pro-personal}$

    where:
    - GHG_{all} is the total annual impact of all the smartphones in a given situation (initial or with lever);
    - $f_{pro-personal}$ is the share of "pro-personal" smartphones in the total number (all) or professional smartphones in the given situation;
    - GHG_{pro}, $GHG_{pro-personal}$ are the annual professional impacts of the smartphone for "pro" and "pro-personal" profiles, respectively.

d. Sources

The daily "personal" utilization profile is a hypothesis chosen to be consistent with the uses observed: it stems from the data of (Kantar TNS, 2015) on the basis of which an average utilization profile was calculated with a weighting built according to the world distribution of the population as a function of age.

The daily "pro" utilization profile is a hypothesis chosen according to the opinions of the experts of the working group to be consistent with the reality of situations in a company.

The hourly smartphone consumption was calculated on the basis of the data of the first deliverable produced by the working group in the framework of this report: the Digital Environmental Repository (DER)[73].

3. Lever no.4: Encouraging the transfer of office documents via a shared resource

a. Description of the lever

Indicator

The indicator chosen is the number of stored copies of a document transferred.

Aim of the lever

The lever proposes to reduce the number of copies of the same document stored on servers used by a company, by privileging the transfer of documents via a platform synchronized with a shared server rather than by email.

b. Hypotheses

To quantify the impact of this lever, we use a case study: correspondents work on the same document whose successive versions they exchange.

Three scenarios are compared:

- Scenario 1 – initial situation, all the documents are transferred by email.
- Scenario 2 – realistic scenario, where the transfers are distributed equally (50% of transfer) between the synchronized platform and transfers by email.
- Scenario 3 – ideal case, where the transfers are done only via the platform.

The general hypotheses are the following:

a. The copies stored only on servers are counted (no data available on the impact linked to the storage of data in the premises locally).
b. It is considered that each correspondent receives all the versions of the document.
c. It is considered that the correspondents save each attachment received on their terminal and that they do not make a copy.
d. It is considered that the terminals used by the correspondents are synchronized with a backup server on which the attachments received are copied once.
e. It is considered that the copies stored on the server of the transfer platform are copied once.

We choose the hypothesis according to which each datum is copied once in order to avoid a strong hypothesis relating to the backup policy: in a real situation the data stored on a server are copied at least once. The hypothesis is taken as being the same for saving emails and backing up the platform in order to build comparable scenarios between them. In reality, there are more copies: the hypothesis is therefore prudent and the result presented here is an underestimation of the real impacts.

[73] Available in "[Lean ICT Materials] REN". Produced by *The Shift Project*.

The copies counted are therefore the copies of the attachments, the documents transferred via the platform (since they are stored on the server used by the platform) and their replication.

The calculation hypotheses are the following:

1. Number of correspondents: 5 people.
2. Number of versions of the document: 4 versions.
3. Size of the document: 1 megabyte (this hypothesis is taken to by in phase with the DER results).
4. Distribution of transfers of documents between the correspondents:

   Scenario 1: 100% of transfers by email.
   Scenario 2: 50% of transfers by email, 50% via the sharing platform.
   Scenario 3: 100% of transfers via the sharing platform.

5. The total number of copies of the document stored for each scenario is the following:

   Scenario 1 - 20 copies:

   - 20 attachments sent (5 correspondents x 4 versions of the document), backed up locally on terminals;
   - Each of these attachments is copied on a backup server;
   - Here, only the data stored on the server are counted, so only the copies.

   Scenario 2 - 14 copies:

   - 10 attachments transferred (half of the versions are transferred by email);
   - Each of these attachments is copied and only these copies are counted.
   - 2 versions are transferred via the platform (and so stored on it);
   - Each of these 2 versions is copied once.

   Scenario 3 - 8 copies:

   - The 4 versions are transferred via the platform (and so stored on it);
   - Each of these 4 versions is copied once.

c. Quantification methodology

The following steps are performed to build this metric:

- For each scenario, the number of documents stored locally was calculated. It is equal to the number of documents transferred by email[74], i.e. the number of documents transferred (product of the number of versions and the number of correspondents[75]) weighted by the share of transfers done by email[76].
- The total number of copies stored on the server was calculated[77].
- The impact of sending an email with an attachment of 1 megabyte – in terms of GHG emissions – is taken from the DER[78] and takes into account the storage on the servers of the messaging service of the email sent and the associated attachment[79].
- The annual impact of storing a byte of data was calculated:
  - The electricity consumption associated with the storage of a byte of data was evaluated on the basis of works and exchanges with a partner of this study, the Groupe Caisse des Dépôts: on the basis of the total volume of data stored and the associated annual electricity consumption, we obtained a magnitude of 1.10^{-9} kWh/byte/year.
  - The associated annual GHG emissions were calculated using the emission factor associated with electricity consumption taken from the DER for the "EU" zone[80].
- For each scenario, the total emissions associated with their sequence were calculated, i.e. the sum of two contributions:

$$GHG_{tot} = N_{email} * GHG_{email} + N_{doc} * n_{doc} * GHG_{byte}$$

where:

  - GHG_{tot} is the total annual impact associated with these transfers in the given scenario;
  - N_{email} is the total number of emails sent;

[74] In accordance with hypothesis b.
[75] In accordance with hypothesis a.
[76] In accordance with hypothesis 4, according to the scenario.
[77] In accordance with hypothesis 5.
[78] Available in "[Lean ICT Materials] REN". Produced by *The Shift Project*.
[79] cf. "Methodological note – Digital Environmental Repository (DER)"
[80] Detailed in "[Lean ICT Materials] REN", tab *"CO_2 Run"*. Produced by *The Shift Project*.

   - GHG_{email} is the impact associated with sending an email;
   - N_{doc} is the number of copies of the document stored on the server;
   - n_{doc} is the size of a copy of the document (1.10^6 bytes);
   - GHG_{byte} is the annual impact associated with the storage of a byte of data on the server.
- For each scenario, we deduce the relative reduction (in %) of the total emissions for the annual storage in comparison to Scenario 1, the initial scenario.

d. Sources

The hypotheses of these calculations were chosen according to the opinions of the experts of the working group to be consistent with the reality of situations in a company.

The GHG emission values were taken from the DER[81] and works performed in collaboration with the Groupe Caisse des Dépôts on the basis of their computer systems.

4. Lever no.5: Metrics of the environmental impact of a digital decision

a. Aim of the lever

Indicator

The indicator chosen here is an example of the metric: the environmental impact of a display screen as a function of its size.

Aim of the lever

The aim is not, in this case, to quantify the effect of the lever, but to give a quantified example of a metric easy to implement and which will allow efficient dialogue between experts and decision-making bodies. It entails demonstrating the pertinence of a larger measure: "Define a language of exchange using standardized metrics (at least at the level of the company) that allows discussion between specialized and strategic decision-making levels".

The calculation here focuses on the following example of the metric: "the environmental impact of a display screen as a function of its size".

b. Hypotheses

1. The display screens are assimilated with the device "Connected TV" described in the Digital Environmental Repository (DER)[82]: the professional display devices are indeed equivalent to if not the same as devices intended for the general public.
2. The hypotheses and results used in the calculations are therefore those of the Digital Environmental Repository (DER) for the connected TV.
3. The impact of a screen is considered through its production and utilization phases.

c. Quantification methodology

The following steps were performed to build this metric:

- The average of screen sizes of different models considered for annual emissions in the utilization phase presented in the DFER was calculated.
- Since the average screen is of a size similar to that used to obtain the GHG emissions in the production phase, the results of the DER for the two phases (production and utilization) were used jointly.
- The annual emissions in the utilization phase were taken from the DER for the "EU" geographic zone.
- We deduced the annual impact of the screen as a function of its size (in $kgCO_2eq$/year/inch): it corresponds to the distribution of the impact of production on the whole lifetime, added to the annual consumption of the device in the utilization phase, all associated with the unit of the diagonal length.

d. Sources

The results used all come from the Digital Environmental Repository (DER), produced by the working group in the framework of this report.

[81] Available in "[Lean ICT Materials] REN". Produced by *The Shift Project*.
[82] Available in "[Lean ICT Materials] REN". Produced by *The Shift Project*.

f. Appendix 6: Least Developed Countries (UN-OHRLLS)[83]

The Least Developed Countries or LDCs represent the poorest and weakest segment of the international community. They represent more than 880 million people (about 12% of the world's population), but less than 2% of world GDP and about 1% of world trade in goods.

Their low level of socioeconomic development is characterized by insufficient human and institutional capacities, low and unequally distributed incomes and the scarcity of national financial resources. They are often subject to crises of governance, political instability and, in certain cases, internal and external conflicts. Their mostly agrarian economies are affected by a vicious circle of low productivity and investment. They depend on several basic products as their main source of exportation and budgetary receipts, making them highly vulnerable to disturbances in foreign trade. Only a handful have been able to diversify in manufacturing activities, though with a narrow range of products in labor intensive industries, that is to say textiles and clothing. These limitations are the source of insufficient mobilization of internal resources, insufficient economic management knowhow, shortcomings in the design and implementation of programs, chronic trade deficits, heavy debt burdens and strong dependency on foreign funds which have maintained the LDCs in a situation of poverty.

The category LDC was officially created in 1971 by the United Nations General Assembly in order to attract international support specifically for the most vulnerable and disadvantaged member States of the United Nations.

The current list of LDCs includes 47 countries (the latest member is South Sudan); 33 in Africa, 13 in Asia and the Pacific and 1 in South America.

LEAST DEVELOPED COUNTRIES

Africa (33)

1	Angola	18	Malawi #
2	Benin	19	Mali #
3	Burkina Faso #	20	Mauritania
4	Burundi #	21	Mozambique
5	Central African Republic #	22	Niger #
6	Chad #	23	Rwanda #
7	Comoros *	24	São Tomé and Príncipe *
8	Democratic Republic of the Congo	25	Senegal
9	Djibouti	26	Sierra Leone
10	Eritrea	27	Somalia
11	Ethiopia #	28	South Sudan #
12	Gambia	29	Sudan
13	Guinea	30	Togo
14	Guinea-Bissau *	31	Uganda #
15	Lesotho #	32	United Republic of Tanzania
16	Liberia	33	Zambia #
17	Madagascar		

Asia Pacific (13)

1	Afghanistan #	8	Nepal #

[83] Information available on the website of UN-OHRLLS: http://unohrlls.org/about-ldcs/about-ldcs/ (consulted on 30/09/2018)

2	Bangladesh	9	Solomon Islands *
3	Bhutan #	10	Timor-Leste *
4	Cambodia	11	Tuvalu *
5	Kiribati *	12	Vanuatu *
6	Lao People's Democratic Republic #	13	Yemen
7	Myanmar		
Latin America and the Caribbean (1)			
1	Haiti *		

* Also a Small Island Developing State
# Also a Landlocked Developing Country

g. Appendix 7: Principles for digital development[84]

At the end of the 2000s, sponsors and intervention agencies started to recognize that digital development plans were fragmented, uncoordinated, segmented and that they had problems adapting and continuing in the long-term. To overcome these challenges, the sponsors and agencies began discussing how they could better understand and share best practices in using digital tools in international development. These conversations resulted in the Innovation Principles of UNICEF of 2009, the Greentree Principles of 2010 and the Design Principles of the United Kingdom, among others.

The Principles for digital development are an attempt to unify these previous principles and form a community of practices for those who work in digital development. The principles for digital development were initially drawn up in consultation with organizations such as the Bill and Melinda Gates Foundation, the Swedish International Development Agency (SIDA), the United Nation Children's Fund (UNICEF), the United Nations Development Program (PNUD), the World Bank, the United States Agency for International Development (USAID) and the World Health Organization (WHO).

PRINCIPLES FOR DIGITAL DEVELOPMENT

The following set of principles represents a concerted effort by donors to capture the most important lessons learned by the development community in the implementation of technology-enabled programs. Having evolved from a previous set of implementer precepts endorsed by over 300 organizations, these principles seek to serve as a set of living guidelines that are meant to inform, but not dictate, the design of technology-enabled development programs.

ONE: DESIGN WITH THE USER

- Develop context-appropriate solutions informed by user needs.
- Include all user groups in planning, development, implementation, and assessment.
- Develop projects in an incremental and iterative manner.
- Design solutions that learn from and enhance existing workflows, and plan for organizational adaptation.
- Ensure solutions are sensitive to, and useful for, the most marginalized populations: women, children, those with disabilities, and those affected by conflict and disaster.

TWO: UNDERSTAND THE ECOSYSTEM

- Participate in networks and communities of like-minded practitioners.
- Align to existing technological, legal, and regulatory policies.

THREE: DESIGN FOR SCALE

- Design for scale from the start, and assess and mitigate dependencies that might limit ability to scale.
- Employ a "systems" approach to design, considering implications of design beyond an immediate project.
- Be replicable and customizable in other countries and contexts.
- Demonstrate impact before scaling a solution.
- Analyze all technology choices through the lens of national and regional scale.
- Factor in partnerships from the beginning, and start early negotiations.

FOUR: BUILD FOR SUSTAINABILITY

- Plan for sustainability from the start, including planning for long-term financial health, e.g., assessing total cost of ownership.
- Utilize and invest in local communities and developers by default, and help catalyze their growth.
- Engage with local governments to ensure integration into national strategy, and identify high-level government advocates.

FIVE: BE DATA DRIVEN

- Design projects so that impact can be measured at discrete milestones with a focus on outcomes rather than outputs.
- Evaluate innovative solutions and areas where there are gaps in data and evidence.
- Use real-time information to monitor and inform management decisions at all levels.
- When possible, leverage data as a by-product of user actions and transactions for assessments.

SIX: USE OPEN DATA, OPEN STANDARDS, OPEN SOURCE, OPEN INNOVATION

- Adopt and expand existing open standards.
- Open data and functionalities, and expose them in documented APIs (Application Programming Interfaces) where use by a larger community is possible.
- Invest in software as a public good.
- Develop software to be open source by default with the code made available in public repositories and supported through developer communities.

SEVEN: REUSE AND IMPROVE

- Use, modify, and extend existing tools, platforms, and frameworks when possible.
- Develop in modular ways favoring approaches that are interoperable over those that are monolithic by design.

EIGHT: ADDRESS PRIVACY & SECURITY

- Assess and mitigate risks to the security of users and their data.
- Consider the context and needs for privacy of personally identifiable information when designing solutions and mitigate accordingly.
- Ensure equity and fairness in co-creation, and protect the best interests of the end-users.

NINE: BE COLLABORATIVE

- Engage diverse expertise across disciplines and industries at all stages.
- Work across sector silos to create coordinated and more holistic approaches.
- Document work, results, processes, and best practices, and share them widely.
- Publish materials under a Creative Commons license by default, with strong rationale if another licensing approach is taken.

For more information, visit DIGITALPRINCIPLES.ORG

[84] https://digitalprinciples.org/

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The Shift Project, carbon transition think tank

The Shift Project is a think tank that works in favor of a post-carbon economy. A non-profit association in the general interest and guided by the requirement for scientific rigor, our mission is to enlighten and influence debate on energy transition in Europe. Our partners are large companies that wish to make energy transition their priority.

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