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APPENDICES OF THE REPORT

Digital technologies in Europe: an environmental life cycle approach

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1. Synthetic overview of the data quality review

Table 58 - Synthetic overview of the data quality review

	Source		TiR		GR		TeR		P
End-user equipment									
Device	NegaOctet	2	All the data have been developed within 2018-2021 period	2	The model is adapted to geographical area through energy mix and transportation scenarios. The mix used is Chinese 90% of the time, and Taiwan the rest of the time	1	The default configurations results of a precise analyse of the market data	1	Measured/calculated and externally verified
Network									
Mobile	NegaOctet	1	All the data have been developed in 2021 based on 2020 data sources	3	Technologies are representative for France	3	The inventory data are representative of the French network in 2020. Those data have been adapted (volume, electricity mix and distance) in order to be representative of the European situation	3	Measured/calculated/ literature and plausibility not checked by reviewer
Fixed	NegaOctet	1	All the data have been developed in 2021 based on 2020 data sources	3	Technologies are representative for France	3	The inventory data are representative of the French network in 2020. Those data have been adapted (volume, electricity mix and distance) in order to be representative of the European situation	3	Measured/calculated/ literature and plausibility not checked by reviewer
Datacentre									
Building	Env. Declaration	3	Valid EPDs have been selected. The EPD declaration have a validity duration of 5 years.	3	Each EPDs have their own geographical area depending on where the product is manufactured. All the data are coming from one country of the EU.	5	Based on one representative manufacturer	1	Measured/calculated and externally verified
Non-IT equipment	Env. Declaration	3	Valid EPDs have been selected. The EPD declaration have a validity duration of 5 years.	3	Each EPDs have their own geographical area depending on where the product is manufactured. All the data are coming from one country of the EU.	5	Based on one representative manufacturer	1	Measured/calculated and externally verified
Non-IT equipment	Material Approach	1	The composition has been collected in 2020	3	Material considered are often produced in Europe.	5	The data includes only material production.	5	We were not able to evaluate the validity of the process in our case.
IT equipment	NegaOctet	2	All the data have been developed within 2018-2021 period	2	The model are adapted to geographical area through energy mix and transportation scenarios. The mix used is Chinese one in 90% of the case, and HK or Taiwan in other case	1	The default configurations results of a precise analyse of the market data	1	Measured/calculated and externally verified
Energy consumption	IAE + EIME	1	Data are representative of 2019	1	The electricity mix is the consumption European mix	1	The electricity mix is the consumption mix based on last IEA inventory	1	Measured/calculated and externally verified
Distribution	ELCD	5	Data have been collected in 2005 and are valid until 2012	1	the transportation data are valid for RER	2	The distribution modes have been grouped through relevant categories within the ELCD database	1	Measured/calculated and externally verified
End of life	ESR	2	Data have been collected in 2016 are valid until 2023	3	The end-of-life database is representative for France	2	The data are representative of the 3 main WEEE eco-organism in France	1	Measured/calculated and externally verified

The methodology used for this data quality review is based on the data quality review requirements from Chapter 7.19.2.2 of the Product Environmental Footprint Guide, version 6.3 (EF= Environmental Footprint).

2. Equipment impacts

This appendix details the individual environmental impact for each equipment or system of all three tiers.

2.1. Tier 1 – End user devices

Data are per single equipment. It considers only the manufacturing, distribution and end of life impacts (use is considered at a global level). When an equipment has several configurations, the values are the averaged results.

Table 59 - End user devices individual impacts - Per device

	Resource use, minerals and metals [kg Sb eq.]	Resource use, fossils [MJ]	Acidification [mol H+ eq.]	Ecotoxicity, freshwater [CTUe]	Climate change [kg CO_2 eq.]	Ionising radiation, human health [kBq U235 eq.]	Particulate matter [Disease occurrence]	Photochemical ozone formation - human health [kg NMVOC eq.]	Raw materials [kg]	Waste production [kg]	Primary energy consumption [MJ]	Final energy consumption (use) [MJ]
Laptops	1.21E-02	2.53E+03	1.18E+00	3.98E+03	1.88E+02	1.17E+02	6.65E-06	5.01E-01	1.41E+01	1.27E+00	3.86E+02	0.0E+00
Tablets	4.44E-03	1.33E+03	6.06E-01	1.84E+03	1.00E+02	3.22E+01	3.40E-06	2.95E-01	3.29E+02	1.71E+02	1.37E+03	0.0E+00
Smartphones	2.96E-03	1.11E+03	5.01E-01	1.41E+03	8.42E+01	1.54E+01	2.80E-06	2.27E-01	1.56E+00	2.62E-01	3.70E+01	0.0E+00
Feature phones	3.54E-03	2.78E+02	1.57E-01	3.96E+02	2.43E+01	5.69E+00	8.46E-07	6.16E-02	1.19E+02	6.67E+01	2.88E+02	0.0E+00
Desktops	2.53E-02	4.96E+03	1.93E+00	8.60E+03	2.80E+02	8.20E+02	1.10E-05	7.55E-01	1.90E+03	5.00E+02	5.10E+03	0.0E+00
Monitors	1.17E-02	1.34E+03	4.82E-01	1.23E+03	6.90E+01	1.44E+02	2.93E-06	2.18E-01	1.22E+01	1.34E-01	1.03E+02	0.0E+00
TVs	4.09E-02	4.52E+03	1.57E+00	4.16E+03	2.34E+02	4.86E+02	9.58E-06	7.05E-01	1.75E+03	7.86E+02	4.67E+03	0.0E+00
Projectors	7.25E-03	9.90E+02	4.41E-01	1.41E+03	6.25E+01	5.20E+01	1.03E-05	2.08E-01	4.03E+02	1.22E+02	1.02E+03	0.0E+00
TV box	1.01E-02	8.68E+02	4.43E-01	1.54E+03	6.17E+01	3.57E+02	2.40E-06	1.66E-01	5.74E+02	1.72E+02	9.03E+02	0.0E+00
Landline phones	1.16E-03	2.15E+02	1.07E-01	2.99E+02	1.33E+01	3.35E+01	5.94E-07	4.11E-02	1.47E+02	3.00E+01	2.21E+02	0.0E+00
Desktop game consoles	2.73E-02	2.40E+03	1.20E+00	4.32E+03	1.70E+02	9.35E+02	6.82E-06	4.71E-01	1.30E+03	4.22E+02	2.49E+03	0.0E+00
Mobile game consoles	3.38E-03	1.54E+03	7.03E-01	1.97E+03	1.16E+02	1.67E+02	3.90E-06	2.79E-01	4.05E+02	8.96E+01	1.60E+03	0.0E+00
Connected speakers	2.72E-03	3.10E+02	1.42E-01	4.29E+02	2.01E+01	3.70E+01	7.74E-07	5.73E-02	1.47E+02	4.62E+01	3.16E+02	0.0E+00
External HDD	1.28E-03	7.97E+01	4.00E-02	2.05E+02	5.73E+00	9.69E+00	3.08E-07	1.60E-02	5.27E+01	3.02E+01	8.26E+01	0.0E+00
External SSD	7.80E-04	1.52E+03	7.12E-01	1.79E+03	1.20E+02	6.32E+00	3.82E-06	2.64E-01	3.10E+02	3.28E+01	1.59E+03	0.0E+00
USB keys & Micro SD	1.61E-04	1.13E+02	5.36E-02	1.38E+02	8.89E+00	2.18E+00	2.87E-07	1.98E-02	2.69E+01	4.08E+00	1.18E+02	0.0E+00
Printers	8.36E-03	2.34E+03	9.47E-01	4.19E+03	1.22E+02	1.65E+02	5.86E-06	4.33E-01	6.53E+02	1.63E+02	2.38E+03	0.0E+00
Other screens	4.98E-02	5.12E+03	1.84E+00	4.59E+03	2.64E+02	5.85E+02	1.13E-05	8.26E-01	2.07E+03	9.54E+02	5.28E+03	0.0E+00
Docking stations	9.20E-03	3.71E+02	2.12E-01	1.03E+03	2.58E+01	4.06E+01	1.12E-06	7.78E-02	3.44E+02	5.92E+01	3.80E+02	0.0E+00

Table 60 - IoT devices individual impacts - Per device

	Resource use, minerals and metals [kg Sb eq.]	Resource use, fossils [MJ]	Acidification [mol H+ eq.]	Ecotoxicity, freshwater [CTUe]	Climate change [kg CO_2 eq.]	Ionising radiation, human health [kBq U235 eq.]	Particulate matter [Disease occurrence]	Photochemical ozone formation - human health [kg NMVOC eq.]	Raw materials [kg]	Waste production [kg]	Primary energy consumption [MJ]	Final energy consumption (use) [MJ]
IoT - Security - Video	4,78E-04	3,75E+02	1,66E-01	5,53E+02	2,53E+01	3,86E+01	9,78E-07	7,01E-02	1,32E+02	1,23E+01	3,89E+02	0,00E+00
IoT - Security - Control	8,25E-05	3,16E+01	1,37E-02	5,62E+01	1,79E+00	1,08E+01	8,15E-08	6,15E-03	2,74E+01	9,72E-01	3,24E+01	0,00E+00
IoT - Auto - Water Heating	3,92E-04	1,01E+02	5,27E-02	1,78E+02	7,21E+00	1,85E+01	2,90E-07	2,02E-02	5,32E+01	6,18E+00	1,05E+02	0,00E+00
IoT - Auto - Street Lights	6,04E-04	3,59E+02	1,49E-01	6,07E+02	2,05E+01	5,76E+01	9,11E-07	7,00E-02	1,69E+02	1,65E+01	3,59E+02	0,00E+00
IoT - Auto - Space	4,68E-04	2,01E+02	8,72E-02	3,48E+02	1,20E+01	3,48E+01	5,22E-07	3,95E-02	9,67E+01	8,86E+00	2,06E+02	0,00E+00
IoT - Auto - Lightning	3,48E-04	9,24E+01	4,91E-02	1,69E+02	6,73E+00	1,47E+01	2,67E-07	1,85E-02	3,78E+01	5,97E+00	9,58E+01	0,00E+00
IoT - Auto - Cooking	3,61E-04	1,08E+02	5,70E-02	1,79E+02	8,08E+00	1,47E+01	3,06E-07	2,09E-02	4,50E+01	5,96E+00	1,12E+02	0,00E+00
IoT - Auto - Audio	5,51E-04	2,79E+02	1,20E-01	4,27E+02	1,76E+01	5,68E+01	7,10E-07	5,31E-02	1,40E+02	1,22E+01	2,78E+02	0,00E+00
IoT - Auto - Appliances	3,62E-04	1,19E+02	6,07E-02	1,97E+02	8,63E+00	1,48E+01	3,33E-07	2,32E-02	4,75E+01	6,30E+00	1,23E+02	0,00E+00
IoT - Smart Meters	7,35E-04	3,38E+02	1,39E-01	5,48E+02	1,90E+01	6,22E+01	8,19E-07	6,53E-02	1,82E+02	1,70E+01	3,37E+02	0,00E+00
IoT - Sensors - Res-WiFi	2,06E-04	7,70E+01	4,04E-02	2,96E+02	6,25E+00	1,25E+01	2,30E-07	1,76E-02	4,04E+01	2,37E+01	7,95E+01	0,00E+00
IoT - Sensors - Res-LE	2,06E-04	7,70E+01	4,04E-02	2,96E+02	6,25E+00	1,25E+01	2,30E-07	1,76E-02	4,04E+01	2,37E+01	7,95E+01	0,00E+00
IoT - Sensors - Industry	2,06E-04	7,70E+01	4,04E-02	2,96E+02	6,25E+00	1,25E+01	2,30E-07	1,76E-02	4,04E+01	2,37E+01	7,95E+01	0,00E+00
IoT - Sensors - Health	2,06E-04	7,76E+01	4,07E-02	2,96E+02	6,30E+00	1,25E+01	2,31E-07	1,77E-02	4,05E+01	2,37E+01	8,02E+01	0,00E+00
IoT - Gateway - Bus	5,80E-04	4,16E+02	1,86E-01	6,25E+02	2,77E+01	5,68E+01	1,05E-06	7,67E-02	1,77E+02	1,56E+01	4,20E+02	0,00E+00
IoT - Gateway - LE to WiFi	5,80E-04	4,16E+02	1,86E-01	6,25E+02	2,77E+01	5,68E+01	1,05E-06	7,67E-02	1,77E+02	1,56E+01	4,20E+02	0,00E+00
IoT - Comm Building Control	5,63E-04	4,17E+02	1,74E-01	6,71E+02	2,50E+01	5,40E+01	1,05E-06	7,98E-02	1,70E+02	1,69E+01	4,20E+02	0,00E+00
IoT - Blinds + Windows	4,78E-04	2,12E+02	9,42E-02	3,96E+02	1,31E+01	2,29E+01	6,96E-07	4,32E-02	1,01E+02	1,82E+01	2,19E+02	0,00E+00

2.2. Tier 2 – Networks

Data are per GB of transmitted data. It averages all technologies (2G, 3G, 4G and 5G for mobile, FTTx and xDSL for fixed-line network).

Table 61 - Network individual impacts – Per GB

Per GB	Mobile network	Fixed line network
Resource use, minerals and metals - kg Sb eq.	5.57E-07	8.51E-07
Resource use, fossils-MJ	7.73E-01	2.46E+00
Acidification - mol H+ eq.	2.02E-04	6.29E-04
Ecotoxicity, freshwater - CTUe	4.39E-01	1.32E+00
Climate change - kg CO2 eq.	3.07E-02	9.60E-02
Ionising radiation, human health - kBq U235 eq.	5.72E-02	1.60E-01
Particulate matter - Disease occurrence	1.45E-09	4.57E-09
Photochemical ozone formation - human health - kg NMVOC eq.	7.45E-05	2.27E-04
Raw materials - kg	1.01E-01	2.71E-01
Waste production - kg	1.53E-02	3.18E-02
Primary energy consumption - MJ	9.09E-01	2.91E+00
Final energy consumption (use) - MJ	2.48E-01	8.53E-01

Data are per subscribers. It averages all technologies (2G, 3G, 4G and 5G for mobile, FTTx and xDSL for fixed-line network).

Table 62 - Network individual impacts – Per subscriber

Per subscribers	Mobile network	Fixed line network
Resource use, minerals and metals - kg Sb eq.	1.47E-03	8.73E-05
Resource use, fossils-MJ	2.04E+03	2.52E+02
Acidification - mol H+ eq.	5.33E-01	6.45E-02
Ecotoxicity, freshwater - CTUe	1.16E+03	1.35E+02
Climate change - kg CO2 eq.	8.12E+01	9.85E+00
Ionising radiation, human health - kBq U235 eq.	1.51E+02	1.64E+01
Particulate matter - Disease occurrence	3.82E-06	4.69E-07
Photochemical ozone formation - human health - kg NMVOC eq.	1.97E-01	2.33E-02
Raw materials - kg	2.66E+02	2.78E+01
Waste production - kg	4.04E+01	3.27E+00
Primary energy consumption - MJ	2.40E+03	2.99E+02
Final energy consumption (use) - MJ	6.54E+02	8.76E+01

2.3. Tier 3 – Data centres

Data are per server of IT room in data centres, per year.

Table 63 - Data centre individual impacts

Per server, per year	Cloud data centres	Traditional data centres	Edge data centres
Resource use, minerals and metals - kg Sb eq.	2.78E-02	2.66E-02	2.78E-02
Resource use, fossils-MJ	8.41E+04	8.42E+04	8.58E+04
Acidification - mol H+ eq.	2.35E+01	2.35E+01	2.39E+01
Ecotoxicity, freshwater - CTUe	5.62E+04	5.61E+04	5.71E+04
Climate change - kg CO2 eq.	3.71E+03	3.71E+03	3.77E+03
Ionising radiation, human health - kBq U235 eq.	4.97E+03	4.97E+03	5.07E+03
Particulate matter - Disease occurrence	1.63E-04	1.63E-04	1.66E-04
Photochemical ozone formation - human health - kg NMVOC eq.	8.77E+00	8.77E+00	8.92E+00
Raw materials - kg	1.07E+04	1.07E+04	1.09E+04
Waste production - kg	1.33E+03	1.30E+03	1.34E+03
Primary energy consumption - MJ	9.83E+04	9.83E+04	1.00E+05
Final energy consumption (use) - MJ	2.55E+04	2.56E+04	2.61E+04

3. Data used in the LCA model

This part details the data sources, assessment and hypotheses for the LCA.

First a global overview over the different life cycles is provided, then each tier and equipment is detailed.

3.1.1. Manufacturing phase

The data have been assessed with the NegaOctet database as of 08/2021.

The NegaOctet database is currently being developed by the NegaOctet consortium (LCIE, APL data center, DDemain, GreenIT.fr). At the time of the publication of the study, the NegaOctet database is ongoing a separate review and will be published by the end of 2021. It is an LCI dataset database, compliant with EF 3.0 methodology.

It is built around 4 levels of granularity:

- Level 0: at component level (wafer, processors, RAM, displays, etc.)
- Level 1: at equipment level (computer, smartphone, server, etc.)
- Level 2: at tier level (datacentre, network, etc.)
- Level 3: at digital services level (sending an email, watching a video, etc.)

In this study, only level 0 and 1 have been used, in line with the granularity of collected information.

Level 0 is based on manufacturer data, literature and products tear-down. For example, the wafer data is based on TSMC 2019 data which have been completed with on-site collection of 4 manufacturers and compared to the literature.

Level 1 is based on manufacturers' data in terms of configuration. Devices can be adapted to a specific configuration in terms of main characteristics (memory, CPU, GPU, display size, etc.).

3.1.2. Distribution phase

The distribution of digital equipment generally follows a complex route, from the warehouse in Asia to the end user in Europe.

By methodological choice, this study does not take into account the distribution from the store to the client.

The transport from the warehouse to the store can follow three pathways:

- Transport by ship (distance from Beijing to Paris as a hypothesis, 20,204 km[1])
- Transport by plane (distance from Beijing to Paris as a hypothesis, 8,330 km[2])
- Transport by train (distance from Beijing to Paris as a hypothesis, 11,661 km[3])

Each time, an additional 1,000 km in truck is added to assess the additional required distance.

Each product does not follow the same pathway. In order to determine the distribution scenario for all products, we used data from Lenovo carbon declarations[4].

Based on the Lenovo carbon declarations and considering the majority of the impacts come from the manufacturing of the chips (the first manufacturer of which is TSMC, in Taiwan[5]), we considered a conservative hypothesis of 100% of IT equipment manufactured in Asia for this European study. For Tier 3 – Datacentres, only the IT equipment were considered as manufactured in Asia. Non-IT equipment and architecture were considered to be manufactured in Europe by hypothesis.

The resulting distribution pathways are as follow:

Table 64 - Distribution scenarios

Tier	Equipment	Plane transport ratio	Ship transport ratio	Rail transport ratio	Manufacturing location	Comment
Tier 1 – User equipment	Desktops	0	1	0	Asia	By hypothesis
	Laptops	0.36	0.60	0.04	Asia	Based on Lenovo carbon declarations
	Storage	0.3	0.08	0.62	Asia	Based on Lenovo carbon declarations
	Tablets (smartphones have been considered as tablets)	0.26	0.58	0.16	Asia	Based on Lenovo carbon declarations
	Other equipment	0	1	0	Asia	By hypothesis
Tier 2 - Network	All equipment	0	1	0	Asia	By hypothesis
Tier 3 - Data centres	IT equipment	0.3	0.08	0.62	Asia	Based on Lenovo carbon declarations
	Non IT equipment	0	0	0	Europe	By hypothesis
	Architecture elements	0	0	0	Europe	Truck: only 100 km. By hypothesis

1 EcoTransIT World. 2021. *EcoTransIT World - Emission Calculator.* [online] Available at: <https://www.ecotransit.org/en/emissioncalculator/> [Accessed 30 September 2021].
2 *Ibid.*
3 *Ibid.*
4 Lenovo.com. 2021. *Regulatory Compliance | ECO Declarations | Lenovo.* [online] Available at: <https://www.lenovo.com/us/en/compliance/eco-declaration/> [Accessed 30 September 2021].
5 Nationalreview.com. 2021. *TSMC: The World's Most Important Company | National Review.* [online] Available at: <https://www.nationalreview.com/2021/04/tsmc-the-worlds-most-important-company/> [Accessed 30 September 2021].

Transport data used is ELCD v3.2 data:

- Plane: Plane; technology mix, cargo; 68 t payload; RER
- Ship: Container ship ocean; technology mix; 27.500 dwt pay load capacity; RER
- Rail: Rail transport; technology mix, electricity driven, cargo; RER
- Truck: Articulated lorry transport; Euro 0, 1, 2, 3, 4 mix; 40 t total weight, 27 t max payload; RER

3.1.3. Use phase

The electricity data is assessed as a European electricity mix.

A more precise approach would have been to use specific countries mixes, but for most equipment, quantitative data were only available at European level, so the distinction by countries is not possible.

In order to be consistent with the data collection period (2019), we chose the most recent available reliable electricity data, coming from IAE for 2018.

The average mix is as follow:

- Coal: 17.65%
- Oil: 1.49%
- Natural gas: 16.65%
- Biofuels: 4.49%
- Waste: 1.33%
- Nuclear: 22.10%
- Hydro: 10.12M
- Geothermal: 0.18%
- Solar photovoltaic: 3.29%
- Solar thermal: 0.13%
- Wind: 10.09%
- Tide: 0.01%
- Other sources: 0.12%
- Municipal wastes: 1.22%
- Wastes (renewable): 0.61%
- Imports: 10.52%
- In-line losses: 5.60%

The CODDE-2020-12 and the ELCD 3.2 databases have been used to assess the electricity consumption. Some additional data have been used for the use phase (fuel consumption, refrigerant leaks) in a marginal way.

3.1.4. End of life phase

The end of life was assessed with the Ecosystem WEEE database as of 2021, with the “no benefits” approach[6].

This approach means that, for the end of life, the study considers that all wastes go to a conventional pathway. Impacts from the collection, treatment, recycling, incineration and landfill of wastes is accounted for. Benefits from recycling or energy valorisation is not taken into account.

This approach is limiting, as an important part of electronic wastes goes to undocumented pathways (illegal or inadequate pathways), for which impacts assessment is impossible.

3.1.5. Tier 1 – User equipment

3.1.5.1. General information

3.1.5.1.1. What are the devices considered in the scope of the study?

Users devices
Mobile phones: Smartphones, Feature phones, power supplies for smartphones Phones (land line)
Tablets, power supplies for tablets
Laptop, power supplies for laptop
Desktop, power supplies for desktop
Docking stations
Projector
Electronic displays: • regular monitors, • special monitors, regular signage display, special signage display • TVs
Tv box Game console Printers External SSD & HDD, USB keys
Connected speakers
IoT connected objects

6 n.d. *About the ecosystem WEEE LCI Database.* [online] Ecosystem. Available at: <https://www.ecosystem.eco/upload/media/default/0001/02/91508a37f34b3a821e4cdff070c4f7483625421c.pdf> [Accessed 30 September 2021].

3.1.5.2. What are the parameters considered related to these devices?

The parameters considered related to these devices are:

1. The Number of units: to inventory the stock of devices.
2. The Energy consumption: to reconstitute the energy consumption of the stock, based either: on the consumption profile of one or more typical model of device, with attribution; or on consistent and recent work found on the same European scope.
3. The Frequency of use: to refine the energy consumption calculations.
4. The Typical lifespan: to attribute the impacts based on the lifespan of the devices.
5. The Penetration rate: to check the coherence between the number of units found, or to complete it when missing.

6. E-waste: To assess the End-of-Life part of the LCA. Due to high uncertainty in data for e-waste flows, please go to the chapter **Treatment of missing data > E-Waste** to learn how we treated this parameter in the study.

3.1.5.1.3. Modelling assumptions and sensitivity analysis

Each piece of equipment will be subject to an LCA based on EIME (ISO 14040/44) based on Bureau Veritas expertise.

By equipment, technical parameters such as screen size, etc. to do a detailed analysis of the equipment have been proposed. No sensitivity analysis on different equipment scenarios based on different technical performance has been performed.

On the contrary, sensitivity analysis on number of equipment and frequency of use of the equipment have been performed.

3.1.5.2. Phones

3.1.5.2.1. Mobile phones

Definition: A mobile phone or cellphone is a portable telephone that can make and receive calls over a radio frequency link while the user is moving within a telephone service area. There are 2 types of mobile phones: smartphones and feature phones. In the developed countries, smartphones have now overtaken the usage of earlier mobile phones.

Number of units in Europe in 2019: 514,746,903 units. The estimation was made using the Digital Economy and Society Index 2020[7], estimating there are 100.2 active mobile broadband SIM cards per 100 people in the EU-28. Based on Eurostat Demographic EU-28 2019 data[8], we calculated that there were 514,746,903 mobile phones units in the EU-28 in 2019. This figure is subjected to some uncertainty due to the possibility to have a double-SIM phones, or on the other hand, 2 phones used by 1 individual with 1 SIM card (for sport for example), and not knowing if smart objects SIM cards were excluded from the figure or not. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Penetration rate: 100.2 % in the EU-28 in 2019. The Digital Economy and Society Index 2020[9] estimates there are 100.2 active mobile broadband SIM cards (smartphones and feature phones) per 100 people in the EU-28. No other data was found to estimate the penetration rate of phones. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

3.1.5.2.2. Smartphones

Definition: A mobile phone that performs many of the functionalities of a computer, typically having a touchscreen interface, internet access from both Wi-Fi and mobile networks, GPS connection and an operating system (OS) capable of running downloaded apps.

Number of units in Europe in 2019: 473,567,151 units. A hypothesis of 92% of smartphones was taken by the authors. No data was found to estimate the percent-

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7 European Comission. 2020. *Digital Economy and Society Index (DESI) 2020.* [online] European Commission, p.32. Available at: <*https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67086*> [Accessed 30 September 2021].

8 Eurostat. 2021. *Population change - Demographic balance and crude rates at national level.* [online] Available at: <*https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_gind&lang=en*> [Accessed 30 September 2021].

9 European Comission. 2020. *Digital Economy and Society Index* (DESI) 2020. [online] European Commission, p.32. Available at: <*https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67086*> [Accessed 30 September 2021].

age of smartphones in the share of mobile phones in the EU. The ICT impact study 2020 estimates to 470,678,600 units[10] the number of smartphones in the EU-27, which would mean there would be more smartphone active than the number of actual active SIM cards in the EU (more than 3% more smartphones than the number of active SIM cards). To stay consistent in our data set, we estimated a share of 92% of smartphones and 8% of feature phones based on the number of active SIM cards. This distribution between smartphones and feature phones is the one that seemed to have the most consistency regarding the two sources found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure, especially as some discrepancies exists between the 2 data found (DESI report 2020[11] and ICT impact study 2020[12]), even if the delta between the two data is limited.

Energy consumption: 3.9 kWh/year/device. The energy consumption of smartphones is based on the average kWh/year energy consumption determined in the ICT impact study 2020, based on the endurance hours (test by GSMArena[13]) of the top 8 most sold smartphones in Europe in 2019 and dividing them by the hours per year. The ICT impact study explains: "The theorical number of charges has then been multiplied by two to provide data for a more realistic life scenario. The charge per year is multiplied by the battery capacity in Wh to give energy consumption per year. The energy consumption is then divided by an efficiency of 75 % to estimate the losses in the phone charger. The average energy consumption is rounded up to 4 kWh which corresponds to the assumed energy consumption of the working plan preparatory study on eco-design and a German report on IT equipment."[14] No other data was found to determine the energy consumption of smartphones. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Frequency of use: 2 hours and 41 minutes per day. The frequency of use is based on the Global Webindex Device Report.[15] No other data was found to determine the frequency of use of smartphones. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Typical lifespan: 2.5 years for personal use.[16] No other data was found at the EU scale to determine the lifespan of smartphones. However, this figure is consistent with internal GreenIT.fr 2021 professional benchmark for smartphones without reuse for France,[17] but a bit higher than the French CREDOC Digital Barometer which is closer to 2 years.[18] In France, the renewal of a smartphone is determined at 37% by software obsolescence of the previous smartphone (no longer worked correctly (32%), OS was obsolete (5%), at 26% by constraint (unusable smartphone 23%), loss or theft (3%), and at 25% by buying "pleasure".[19] The absence of European sources to estimate the robustness of the lifespan gives some uncertainty to the figure.

Penetration rate: 76% smartphone adoption in 2019 in Europe (market region).[20] No other data was found to estimate the penetration rate of smartphones. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

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10 2020. *ICT Impact Study Prepared by VHK and Viegand Maagøe for the European Commission, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

11 European Comission. 2020. *Digital Economy and Society Index (DESI) 2020.* [online] European Commission, p.32. Available at: <https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67086> [Accessed 30 September 2021].

12 2020. *ICT Impact Study Prepared by VHK and Viegand Maagøe for the European Commission, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

13 Gsmarena.com. n.d. *Battery life tests - GSMArena.com.* [online] Available at: <https://www.gsmarena.com/battery-test.php3> [Accessed 30 September 2021].

14 2020. *ICT Impact Study Prepared by VHK and Viegand Maagøe for the European Commission, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.119. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

15 Globalwebindex.com. 2020. *Consumer Trends in Digital Device Usage - GlobalWebIndex.* [online] Available at: <https://www.globalwebindex.com/reports/device> [Accessed 30 September 2021].

16 2020. *ICT Impact Study Prepared by VHK and Viegand Maagøe for the European Commission, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.112. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

17 Club Green IT. 2021. *GreenIT.fr Benchmark 2021 (professionals).* [online] Available at: <https://club.greenit.fr/benchmark2021.html> [Accessed 30 September 2021].

18 CREDOC. 2021. *Baromètre du numérique 2021.* [online] CREDOC. Available at: <https://www.credoc.fr/publications/barometre-du-numerique-edition-2021> [Accessed 30 September 2021].

19 *Ibid.*

20 GSMA, 2020. *The Mobile Economy 2020.* [online] Available at: <https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/03/GSMA_MobileEconomy2020_Global.pdf> [Accessed 30 September 2021].

Characteristics: the smartphone model is a weighted mix of three configurations, with the following characteristics:

Table 65 - Smartphones characteristics

Configuration	Low-end x-(<€200)	Mid-range (€200<€600)	High-end/ Premium (€600+)
Repartition*	50%	30%	20%
Device weight (kg)	0.204	0.189	0.202
Display size (inches)	6.59	6.57	6.72
Display technology	LCD	AMOLED	OLED
Processor	MediaTek Helio G85	SnapdragonTM 730G	Exynos 990
RAM (GB)	6	7	11
SSD capacity (GB)	128	160	341
PWB surface (cm²)	125.16	117.94	122.36
Battery weight (g)	84	79	77

The characteristics were defined based on the authors' market knowledge, in order to use an average configuration of smartphones in respect of the 3 categories. The percentage applied to weight each of the 3 categories is a rough hypothesis based on IDC Worldwide Smartphone Price band Forecast in 2019 (source: IDC, 2020. [online] Available at: <https://www.idc.com/getdoc.jsp?containerId=prUS46865120> [Accessed 30 September 2021].)

3.1.5.2.3. Feature phones

Definition: A mobile phone that retains the form factor of earlier generations of mobile phones, typically having press-button, small non-touch LCD display, a microphone, a rear-facing camera, GPS services. To compare them to smartphones, there are sometimes called dumb phones. Feature phones provide voice calling and text messaging functionality and some basic mobile apps: calendar, calculator, multimedia apps and basic mobile web browser.

Number of units in Europe in 2019: 41,179,752 units estimated. A hypothesis of 8% of feature phones was taken. No data was found to estimate the percentage of feature phones in the share of mobile phones in the EU. The ICT impact study 2020 estimates to 470,678,600 units the number of smartphones in the EU-27, which would mean there would be more smartphone active than the number of actual active SIM cards in the EU (more than 3% more smartphones than the number of active SIM cards). To stay consistent in our data set, we estimated a share of 8% of feature phones and 92% of smartphones based on the number of active SIM cards. This distribution between smartphones and feature phones is the one that seemed to have the most consistency regarding the two sources found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to this figure, especially as some discrepancies exists between the 2 data found (DESI report 2020[21] and ICT impact study 2020[22]), even if the delta between the two data is limited.

Moreover, this approach integrates some uncertainty coming from that some feature phones might have a double SIM card, and some phones might be still active with shared SIM cards.

Energy consumption: No data were found regarding energy consumption. Energy consumption has been estimated based on the frequency of use and power usage of devices (0.5W in active mode, 0.007W in stand-by mode)[23]. With the frequency of use, the total yearly energy consumption is estimated to 0.09 kWh/year. No more recent data could be found. This brings a low level of uncertainty since it only applies to energy consumption of very small devices which only represent a very small part of overall impacts of ICT.

Frequency of use: Recent data on feature phone frequency of use could not be found, but the study "Life Cycle Environmental Issues of Mobile Phones", 2005 by Nokia[24] indicates a 11 minutes per day of conversation. This brings some uncertainty, but regarding the overall study this uncertainty is low since it only applies to 1 type of device which represents a very small part of overall impacts of ICT.

Typical lifespan: 2.5 years (by hypothesis, based on smartphone values). No specific data associated to feature phones lifespan was found.

21 European Comission. 2020. *Digital Economy and Society Index (DESI) 2020.* [online] European Commission, p.32. Available at: <https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67086> [Accessed 30 September 2021].

22 2020. *ICT Impact Study Prepared by VHK and Viegand Maagøe for the European Commission, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

23 Based on previously performed studies from 2009-2013, for Vodafone and SFR, based on 100+ feature phones.

24 Singhal, P., 2005. *Integrated Product Policy Pilot Project Stage I Final Report: Life Cycle Environmental Issues of Mobile Phones.* [online] Available at: <https://www.researchgate.net/publication/239545987_Integrated_Product_Policy_Pilot_Project_Stage_I_Final_Report_Life_Cycle_Environmental_Issues_of_Mobile_Phones> [Accessed 30 September 2021].

Characteristics: the feature phone model has the following characteristics:

Table 66 - Feature phones characteristics

Configuration	Feature phone
Repartition (by hypothesis)	100%
Device weight (kg)	0.13
Display size (inches)	1.8
Display technology	TFT

3.1.5.2.4. Phones (land line)

Definition: "A phone that is connected to a landline. Can be either fixed to a location because it is cable connected or a wireless handset (typically DECT phone) that requires charging in a stand, which may also function as a base providing the connection between the handset and the landline."[25]

Number of units in Europe in 2019: 321,382,299 units. The stock of landline phones is established by the ICT impact study 2020,[26] and has been calculated using annual sales presented in the same report and applying a normal distribution assuming a typical lifespan of 8 years based on a German study[27]. The data was interpolated to obtain 2019 and extrapolated using a factor proposed by the source report to obtain EU-28 based on the number of households. No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure. No other source was found to estimate the power consumption of land line phones.

Energy consumption: 17.57 kWh/year/device. The kWh/year/device consumption of land line phones was estimated based on 2.7 W in active use and 2 W in stand-by mode, with 10 minutes active use/day. Based on a German study. [28] There is a small uncertainty due to the fact the study was published 4 years before our 2019 reference year, but this uncertainty is limited because land-line phones accounts for only a very small part of the equipment considered.

Frequency of use: No data were found regarding frequency of use of land line phones.

Typical lifespan: 8 years, based on the German study previously cited.[29] This figure was compared to internal GreenIT benchmark 2021 (professionals), [30] which gives a typical lifespan of 7 years without reuse and of 10 years with reuse. Therefore, the lifespan of 8 years was estimated as consistent. The absence of source at the EU scale and more recent makes it more difficult to estimate the robustness of the data and bring some level of uncertainty to the figure.

Penetration rate: No data were found regarding penetration rate of land line phones.

Characteristics: the landline phone model has the following characteristics:

Table 67 - Land line phones characteristics

Configuration	Land line phone
Repartition (by hypothesis)	100%
Device weight (kg)	0.522
Display technology	Monochrome
Battery	NiMH AAA

3.1.5.3. Tablets

Definition: "A product which is a type of notebook computer that includes both an attached touch-sensitive display and can have an attached physical keyboard."[31]

Number of units in Europe in 2019: 156,091,954 units. The stock of tablets is established by the ICT impact study 2020,[32] and has been calculated using annual sales presented in the same report and applying a normal distribution assuming a typical lifespan of 3 years, as the mean and the standard deviation of 1. The data

25 Definition from: VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.109. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

26 *Ibid*, p.113.

27 Dr. Lutz Stobbe, Marina Proske, Hannes Zedel (Fraunhofer IZM); Dr. Ralph Hintemann, Dr. Jens Clausen, Dr. Severin Beucker (Borderstep), 2015. *Entwicklung des IKT-bedingten Strombedarfs in Deutschland.* [online] p.169. Available at: <https://www.bmwi.de/Redaktion/DE/Downloads/E/entwicklung-des-ikt-bedingten-strombedarfs-in-deutschland-abschlussbericht.pdf?__blob=publicationFile&v=3> [Accessed 30 September 2021].

28 *Ibid*, p.168.

29 *Ibid*, p.169.

30 Club Green IT. 2021. *GreenIT.fr Benchmark 2021 (professionals).* [online] Available at: <https://club.greenit.fr/benchmark2021.html> [Accessed 30 September 2021].

31 Definition from: VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.108. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

32 *Ibid*, p.113.

was interpolated to obtain 2019 and extrapolated using 0.87 factor proposed by the ICT impact study to obtain EU-28.[33] No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Energy consumption: 19.4 kWh/year/device in 2020. Only one source (ICT impact study, 2020) was found.[34] The source indicates a consumption of 18.6 kWh/year/device in 2020, and a consumption for 2015, without more indication of the methodology used to estimate this consumption. The results were interpolated to estimate the 2019 value. There is a high level of uncertainty on this area due to the absence of other sources to estimate tablet consumption, whether it is tablet average consumption during use or standby mode, and average tablet daily use in the EU-28.

Typical lifespan: 3 years based on the ICT impact study.[35] This is consistent with the lifespan used by the ADEME.[36] This figure 1 year less than the figures GreenIT.fr professional benchmark of 4 years without reuse and 4.6 years with reuse. Since GreenIT.fr benchmark only applies to professionals, we used the lifespan proposed in the ICT report. No other data was found. The absence of other sources to estimate the robustness of the data gives some uncertainty to the figure.

Penetration rate: 53.89 % in the EU-28 in 2020 (based on household penetration). The calculation was made based on two complementary sources, one about tablet user penetration rate in Central & Eastern Europe (per country in 2020)[37], and the second one about tablet penetration in Western Europe in 2020 (forecast 2016)[38], expressed in percent of internet users. In order to find the global EU-28 penetration rate we completed the Western Europe study with the percent of internet users per country based on different sources[39]. We calculated the number of users per EU-28 country by applying the user penetration rate of each country to its national demographics based on Eurostat demographic repartition. No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Characteristics: the tablet model is a weighted mix of three configurations, with the following characteristics:

Table 68 – Tablets characteristics

Configuration	Low-end (<€300)	Mid-range (€300<€900)	High-end/ Premium (€900+)
Repartition (by hypothesis)*	20%	60%	20%
Device weight (kg)	0.465	0.498	0.471
Display size (inches)	10.2	10.3	11.1
Display technology	LCD Tactile	LCD Tactile	LCD Tactile
Processor	Huawei Kirin 659	A10 Fusion	Apple A12 Bionic
RAM (GB)	4	4	6
SSD capacity (GB)	32	256	512
PWB surface (cm^2)	400.84	421.35	461.14
Battery weight (g)	156.2	205.8	216.4

*The hypothesis is based on a Gaussian approach, considering most customers buy mid-range tablets, and fringes buy low-end or high-end tablets.

3.1.5.4. Laptops

Definition: "A computer designed specifically for portability and to be operated for extended periods of time either with or without a direct connection to an AC power source. It has an integrated display."[40] Designated as notebook in the ICT impact study.

33 *Ibid*, p.3.
34 *Ibid*, p.118.
35 *Ibid*, p.112.
36 Base-impacts.ademe.fr. 2021. *Base Impacts® - Documentation - folder 1.2. AE – "Référentiels secotriels & Echelles" - "Equipment électrique et électronique".* [online] Available at: <https://www.base-impacts.ademe.fr/gestdoclist> [Accessed 30 September 2021].
37 Statista. 2020. *Key Market Indicators - Tablet reach in CEE region 2020 | Statista.* [online] Available at: <https://www.statista.com/statistics/1134069/tablet-reach-in-cee-region/> [Accessed 30 September 2021].
38 AdWorld.ie. 2016. *Ireland ranks 5th in Europe for tablet ownership - AdWorld.ie.* [online] Available at: <https://www.adworld.ie/2016/04/08/ireland-ranks-5th-europe-tablet-ownership/> [Accessed 30 September 2021].
39 UK : source ONS Gov UK; Netherlands, Denmark, Ireland, Sweden, Spain, Germany, France, Italy, Finland, Portugal, Malta, Luxembourg, Austria, Belgium, Cyprus, Greece: source Internet WorldStats.
40 Definition from: VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.108. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

Number of units in Europe in 2019: 273,333,333 units. The stock of laptops is established by the ICT impact study 2020,[41] and has been calculated using annual sales presented in the same report and applying a normal distribution assuming a typical lifespan of 5 years, as the mean and the standard deviation of 1. The data was interpolated to obtain 2019 and extrapolated using 0.87 factor proposed by the source report to obtain EU-28. No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Energy consumption: 30.96 kWh/year/device. The energy consumption of a laptop is based on the ICT impact study 2020.[42] The data was interpolated to obtain 2019 based on 2015 and 2020 energy consumption, the repartition of the different categories was made based on the Task 7 report and ICT impact study data for years 2015-2020.[43] No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Frequency of use: 3.56 hours. The Global Web Index figure estimates to 3 hours and 27 minutes laptops frequency of use. [44] According to the ADEME, the frequency of use of a laptop is 3.8h/daily and professional use is 3.5h/daily. [45] Those two sources are consistent. We estimated to 3.56 hours the frequency of use based on these two data, to limit the small uncertainty due to difference of geographical scope.

Typical lifespan: 4 years. A lifespan of 4 years was applied based on Authors' knowledge of ICT. The ADEME uses a 4-year lifespan (ADEME, 2017) too.[46] The ICT impact study uses a 5-year lifespan, [47] which seems slightly more than internal GreenIT.fr benchmark (professional) 2021 figures[48], if a high percentage of reused laptop is included.

Penetration rate: No data were found regarding the penetration rate of laptops.

Characteristics: the laptop model is a weighted mix of three configurations, with the following characteristics:

Table 69 - Laptops characteristics

Configuration	Chromebook	Office Equipment	Gaming
Repartition (based on the ICT impact study*)	39.5%	48.8%	11.7%
Device weight (kg)	1.5	1.54	2.3
Display size (inches)	14.5	14.5	15.6
Display technology	LCD	LCD	LED
Processor	AMD Ryzen 5	Intel® Core™ i7 de 8e génération	Intel Core I5
RAM (GB)	13	8	16
SSD capacity (GB)	427	564	512
HDD capacity (GB)	0	0	0
PWB surface (cm^2)	52.93	62.03	88.22
Graphic card	Integrated	Integrated	NVIDIA Ampere GeForce RTX 2060 6Go
Battery weight (g)	330	165	287
EPS (g)	245	211	208

* VHK and Viegand Maagøe for the European Commission. 2020. ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT. [online] European Commission - Energy, p.111. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021]. The data was interpolated to obtain 2019 based on 2017 and 2020 repartition of the different categories from Task 7 report. ICT impact study was used for the repartition regrouping categories, except for Chromebook type of laptops that is based on authors' assumption. No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

41 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.113. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021]; Maagøe, V., 2018. Internal modelling files that supports the computer regulation.

42 *Ibid*, p.118.

43 Maagøe, V. and VITO, 2018. *Preparatory study on the Review of Regulation 617/2013 (Lot 3) Computers and Computer Servers, Task 7 report Policy measures and scenario analyses, Final Version.* [online] Available at: <https://computerregulationreview.eu/sites/computerregulationreview.eu/files/Preparatory%20study%20on%20review%20computer%20regulation%20-%20Task%207%20VM%2019072018.pdf> [Accessed 30 September 2021].

44 GlobalWebIndex, 2020. *GlobalWebIndex's flagship report on device ownership and usage.* [online] p.10 PC/Laptop/Tablet time spent in Europe. Available at: <http://globalwebindex.com> [Accessed 30 September 2021].

45 Base-impacts.ademe.fr. 2021. *Base Impacts® - Documentation - folder 1.2. AE – "Référentiels secotriels & Echelles" - "Equipment électrique et électronique".* [online] Available at: <https://www.base-impacts.ademe.fr/gestdoclist> [Accessed 30 September 2021].

46 *Ibid.*

47 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.112. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021]

48 Club Green IT. 2021. *GreenIT.fr Benchmark 2021 (professionals).* [online] Available at: <https://club.greenit.fr/benchmark2021.html> [Accessed 30 September 2021].

3.1.5.5. Desktops

Definition: "A computer where the main unit is intended to be in a permanent location and is not designed for portability. It is only operational with external equipment such as display, keyboard and mouse."[49]

Number of units in Europe in 2019: 125,266,207 units. The stock of desktops is established by the ICT impact study 2020.[50] The data was interpolated to obtain 2019 and extrapolated using 0.87 factor proposed by the source report to obtain EU-28. No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Energy consumption: 104.39 kWh/year/device. The energy consumption of a desktop is based on the ICT impact study 2020.[51] The data was interpolated to obtain 2019 based on 2015 and 2020 energy consumption repartition of the different Energy Star categories. No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Desktops can be divided in N sub-categories (0, I1, I2, I3) depending on their performance, from category 0 for the less performant to I3 for the most performant, based on the Energy Star rules: I=Integrated/Switchable graphics card; D=Discrete; the number of processors cores multiplied with the base clock speed (I1, I2, I3, D1, D2). The Energy Star rules are such that the manufacturer should declare the worst-case processor in each category for which it claims conformity with Energy Star.

Frequency of use: 3.54 hours. The Global Web Index figure estimates to 3 hours and 27 minutes desktops frequency of use. [52] According to the ADEME, the frequency of use of a desktop is 3.45h/daily and professional use is 3.5h/daily. [53] These two figures are consistent. We estimated to 3.54 hours the frequency of use based on these two data, to limit the small uncertainty due to difference of geographical scope.

Typical lifespan: A lifespan of 5.5 years was applied, based on authors' desktop lifespan knowledge and internal GreenIT.fr benchmark (professional) 2021.[54]

Table 70 - Desktops characteristics

Configuration	Categories 0 and I1	Category I2	Category I3	Category D1	Category D2
Repartition (based on the ICT impact study*)	18%	16%	31%	14%	21%
Device weight (kg)	2.2	2.4	4.8	6.8	10.5
Power supply (kg)	0.34	1.2	3.27	1.7	1.66
PWB surface (cm²)	289	359.1	590.49	686.25	686.25
Processor	Intel Celeron G3930	Intel Pentium G4560	AMD Ryzen 5 1500X	AMD Ryzen 5 1600	AMD Ryzen 7 1700X
RAM (GB)	4	8	8	16	16
Graphic card	Integrated	MSI GeForce GTX 1050 2GT LP	Sapphire Radeon RX 570 Nitro+ 4Go	GeForceRTX2080	GeForceRTX3080
SSD capacity (GB)	250	250	250	500	1,000
HDD capacity (GB)	0	1,000	1,000	2,000	2,000
DVD reader (kg)	0.7	0.7	0.7	0.7	0.7

VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.111. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021]. The data was interpolated to obtain 2019 based on 2017 and 2020 repartition of the different categories from Task 7 report. ICT impact study was used for the repartition regrouping categories. No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

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49 Definition from: VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.108. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

50 *Ibid*, p.111.

51 *Ibid*, p.118.

52 GlobalWebIndex, 2020. *GlobalWebIndex's flagship report on device ownership and usage.* [online] p.10 PC/Laptop/Tablet time spent in Europe. Available at: <http://globalwebindex.com> [Accessed 30 September 2021].

53 Base-impacts.ademe.fr. 2021. *Base Impacts® - Documentation - folder 1.2. AE – "Référentiels secotriels & Echelles" - "Equipment électrique et électronique".* [online] Available at: <https://www.base-impacts.ademe.fr/gestdoclist> [Accessed 30 September 2021].

54 Club Green IT. 2021. *GreenIT.fr Benchmark 2021 (professionals).* [online] Available at: <https://club.greenit.fr/benchmark2021.html> [Accessed 30 September 2021].

The ICT impact study,[55] as well as the ADEME,[56] uses a 6-year lifespan. This is slightly more than the authors desktop lifespan knowledge, and internal GreenIT.fr benchmark (professional) 2021 figures if a percentage of reused desktops is included. To be consistent, a 5.5 lifespan was applied. The absence of lifespan figures at the Europe scale brings some uncertainty.

Characteristics: the desktop model separated between the personal and professional configuration.

For the personal configuration, it is a weighted mix of five configurations, with the characteristics displayed in Table 68, page 14.

3.1.5.6. Docking stations

Definition: A dock in which the laptop is plugged-in to provide a simplified way to connect different and multiple equipment (power signaling, wireless mice, smartphones, ...). It can allow some laptop computers to become a substitute for a desktop computer, without sacrificing the mobile computing functionality of the machine.

Number of units in Europe in 2019: 6,696,300 units estimated for the EU-28. Only one private source was found to estimate the number of docking stations in the EU market (Research Nester, 2020).[57] We used a GDP ratio to estimate the number of units for 2019 in the EU-28: the Europe figures of the report includes U.K., Germany, France, Italy, Spain, Hungary, Belgium, Netherlands, Luxembourg, NORDIC, Poland, Turkey, Russia, Rest of Europe. The Europe 2020 figures of the Research Nester report accounts for 19.87 % of the global docking station market. Our hypothesis is that the EU-28 represents 85 % of the Europe market in this report, which would mean 16.89 % of the global market. No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

Energy consumption: No data were found regarding energy consumption. Energy consumption has been estimated based on the frequency of use and power usage of devices (1W in active mode by hypothesis, leading to 1.28 kWh/year consumption). The absence of sources to estimate the robustness of the data gives a very high level of uncertainty to the figure.

Frequency of use: No data were found regarding docking stations frequency of use. By hypothesis, it has been considered a professional use (3.5 hours per day, similar to laptop professional use). The absence of sources to estimate the robustness of the data gives a very high level of uncertainty to the figure.

Typical lifespan: 5 years. No data were found regarding lifespan of docking stations. The lifespan has been estimated on the hypothesis of GreenIT.fr professional benchmark 2021, to a 5-year lifespan.[58] The absence of other sources to estimate the robustness of the data gives a very high level of uncertainty to the figure.

Penetration rate: No data were found regarding docking stations penetration rate.

Characteristics: the docking station model is single configuration, with the following characteristics:

Table 71 - Docking stations characteristics

Configuration	Docking stations
Repartition (by hypothesis)	100%
Device weight (kg)	0.9

3.1.5.7. Projectors

Definition: "A projector is an optical device, for processing analogue or digital video image information, in any broadcasting, storage or networking format to modulate a light source and project the resulting image onto an external screen. Audio information, in analogue or digital format, may be processed as an optional function of the projector."[59]

Number of units in Europe in 2019: 7,084,138 units. The stock of projectors is established by the ICT impact study 2020,[60] and has been calculated using

55 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.112. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

56 Base-impacts.ademe.fr. 2021. *Base Impacts® - Documentation - folder 1.2. AE – "Référentiels secotriels & Echelles" - "Equipment électrique et électronique".* [online] Available at: <https://www.base-impacts.ademe.fr/gestdoclist> [Accessed 30 September 2021].

57 Research Nester, 2020. *Global Docking Station Market 2018–2020.*

58 Club Green IT. 2021. *GreenIT.fr Benchmark 2021 (professionals).* [online] Available at: <https://club.greenit.fr/benchmark2021.html> [Accessed 30 September 2021].

59 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.85. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

60 *Ibid*, p.86.

annual sales presented in the same report and applying a normal distribution assuming a typical lifespan of 5 years. The same report underlines, on one hand, that this is slightly more than the projections in EIA, which estimate sales to 0.725 units in 2020 and a stock of 5.4 million units in 2020; and on the other hand, the high uncertainty of applying global numbers to the EU. The data was interpolated to obtain 2019 based on 2015 and 2020 ICT impact study data and extrapolated to EU-28 using the factor proposed by the ICT impact study. A private exchange with industry representatives confirmed the order of magnitude ad the trend described by the ICT impact study regarding the evolution of the projector market in the EU. Moreover, we collected the information of 855,400 units sold in 2020 for the Western Europe market, from a primary source. By applying a 25% ratio to add the Eastern Europe market (based on GDP and population), and a typical lifespan of 5 years, we obtain a stock of 5,336,200 units, which is coherent with the ICT and EIA 2018 estimations cited in the ICT impact study for EU-27. Therefore, we estimate the data used consistent.

Energy consumption: an average of 200 kWh/year/device, based on the DG GROW Lot 3 study[61], cited in the ICT impact study.[62] The energy consumption is determined from a representative 24-hour cycle for the most common projector's types in the EU:

- "Classroom projectors: on-play 3 h at 275W, standby 6 h at 1W, off-mode 15 h at 0.5W, total 318 kWh/a, 871 Wh/d, 36 W.
- Office projectors: on-play 1.5h at 250W, standby 8h at 1W, off-mode 14.5h at 0.5W, total 158 kWh/a, 433 Wh/d, 18 W.
- Home projectors: on-play 0.5h at 200W, standby 20h at 1W, off-mode 3.5h at 0.5W, total 49 kWh/a, 134 Wh/d, 5.6 W."[63]

No other consistent data was found. There is a small uncertainty on energy consumption of video projectors since most recent video projectors have a slightly smaller consumption than 10 years older projectors used in the DG GROW Lot 3 study. This difference may be not significant considering the overall number of projectors compared to other sources of impact.

Frequency of use: an average on-mode use of 2.1 hours per day, based on the DG GROW Lot 3 study cited in the ICT impact study.[64] An average on-mode use of 2.1 hours per day was used, based on the DG GROW Lot 3 study cited in the ICT impact study. No other consistent data was found. There is a small uncertainty on the frequency of use of the projectors since the DG GROW Lot 3 study was published in 2010. This difference may be not significant considering the overall number of projectors compared to other sources of impact in ICT.

Typical lifespan: 5 years based on the ICT impact study,[65] which is coherent with our internal GreenIT.fr professional benchmark findings.[66] No other data was found. The absence of other sources to estimate the robustness of the data brings some uncertainty to the figure.

Penetration rate: No data were found regarding penetration rate of projectors.

Characteristics: the projector model is a single configuration, with the following characteristics:

Table 72 - Projectors characteristics

Configuration	Projectors
Repartition (by hypothesis)	100%
Device weight (kg)	4.14

61 AEA with Intertek, 2010. *Lot 3 – Sound and imaging equipment, Ecodesign preparatory study for EC DG Grow.*

62 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.88. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

63 *Ibid*, p.87-88.

64 *Ibid*, p.88.

65 *Ibid*, p.86.

66 Club Green IT. 2021. *GreenIT.fr Benchmark 2021 (professionals).* [online] Available at: <https://club.greenit.fr/benchmark2021.html> [Accessed 30 September 2021].

3.1.5.8. Electronic displays

3.1.5.8.1. Definition:

"A display screen and associated electronics that, as its primary function, displays visual information from wired or wireless sources"[67]

Table 73 - Electronic displays categories

Product category	Displays in scope*
Regular monitors	PC monitors (undifferentiated whether for desktops, thin client, or external laptop second screens)
Special monitors	Security monitors, medical displays (incl. integrated), broadcasting displays, professional displays (CAD, graphics)
Regular signage display	Retail & banks indoor displays (excl. ATM), meeting rooms (incl. video conference), classrooms (incl. smart boards), airports/train/metro stations regular external and integrated signage displays (traffic info & advertising display, passenger TV in plane or train)*, bars, hotels (public area), restaurants, waiting rooms (e.g. healthcare), outdoors
Special signage display	Super large (>100°, video-wall), excl. projectors
Televisions	Regular TV, Hospitality TV (hotel rooms & other lodgings, hospital beds)

* This product categories segmentation mainly relies on the Table 42 in VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.77. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

***Note:** The integrated displays inventoried in the ICT impact study (table 42)*[68] *were excluded from this inventory, first, to avoid double accounting from other categories (mobile devices, laptops, tablets, smart meters...), second, since the rest of the equipment in this category is at the edge of the scope of what can be considered as an ICT device (ATMs, vending machines, ventilation units, microwaves, refrigeration...). Only the integrated displays in means of transport (traffic info & advertising display, passenger TV in plane or train) have been considered, in the scope of our product category of regular signage display.*

3.1.5.8.2. Regular monitors

Number of units:

We applied the same method than the ICT impact study: the number of units and the average surface diagonal (in inch) and area (in dm^2) allows us to estimate the total area of screen, expressed in km^2.

Lately, a new technology has emerged: OLED screens are now considered the state-of-the-art. The environmental impacts are different from classic LCD TV.

Repartition is not known for monitors, but based on TV data, in 2019, 1.4% of sold TV worldwide were OLED, 2.7% were QLED, and 95.9% were LCD[69].

Table 74 - Regular monitors number of units

Surface diag. Inch	Surface area dm^2	Stock units	Total area in km^2	Note
24	16	54,397,952	15.02	ICT impact study + updates*

* Stock updated based on share of monitor by type used in VHK and Viegand Maagøe for the European Commission. 2020. ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT. [online] European Commission - Energy, p.77. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021]; which are 2014 forecasts for 2020, and based on updated estimations for EU28 based on IDC worldwide shipments between 2012 and 2020.

***Note:** the number of regular monitors is surprisingly low compared to the number of desktop computers (125,266,207 units). Several reasons can partially explain this difference:*

Uncertainty in the collected data (will be addressed in the sensitivity analysis)

Use of some desktops as small servers that do not necessitate a monitor full time

Use of some desktops with a monitor from another category (TV screens for example)

67 European Commission, 2019. *Commission Regulation (EU) 2019/2021 of 1 October 2019 laying down ecodesign requirements for electronic displays pursuant to Directive 2009/125/EC of the European Parliament and of the Council, amending Commission Regulation (EC) No 1275/2008 and repealing Commission Regulation (EC) No 642/2009 (Text with EEA relevance.).* [online] Available at: <https://op.europa.eu/en/publication-detail/-/publication/648e809d-1729-11ea-8c1f-01aa75ed71a1/language-en/format-HTML/source-118558953> [Accessed 30 September 2021].

68 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.77. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

69 TrendForce, WitsView and Statista, 2020. *Global TV market share by type 2020 | TrendForce; WitsView; Statista.* [online] Statista. Available at: <https://www.statista.com/statistics/818389/world-tv-market-share-by-type/> [Accessed 30 September 2021].

Energy consumption: an average of 70 kWh/year/device, based on ICT impact study.[70]

Frequency of use: The frequency of use we used is therefore 3.8h/day in active mode, 8h/day in stand-by mode, and 12,2h/day in off mode, based on a mix between the French labelling scheme[71].

Typical lifespan: 6 years without reuse based on the GreenIT.fr professional benchmark.[72]

Penetration rate: No information on penetration rate.

Characteristics: the monitor model is a weighted mix of two configurations, with the following characteristics (see Table 75):

Table 75 - Regular monitors characteristics

Configuration	LCD monitor	OLED monitor
Repartition (based on Trendforce, Witsview data*)	98.6%	1.4%
Device weight (kg)	3.64	11.5
Display size (inches)	24	39
Display technology	LCD	OLED
PWB surface (cm²)	1783.68	2014.01

* TrendForce, WitsView and Statista, 2020. *Global TV market share by type 2020 | TrendForce; WitsView; Statista.* [online] Statista. Available at: <https://www.statista.com/statistics/818389/world-tv-market-share-by-type/> [Accessed 30 September 2021].

3.1.5.8.3. Special monitors, Regular signage display & Special signage display

Number of units:

We applied the same method than the ICT impact study: the number of units and the average surface diagonal (in inch) and area (in dm²) allows us to estimate the total area of screen, expressed in km² (see Table 76 below).

Table 76 - Special monitors number of units

Type	Surface diag. Inch	Surface area dm²	Stock units in 2019	Total area in km²	Note
Special monitors	24	16	5,708,427	0.91	ICT impact study + updates[i]
Regular signage display - Exc. Integrated in means of transport	55	83	20,147,390	16.81	ICT impact study + updates[i]
Regular signage display only integrated in means of transport: Traffic info & advertising display	24	16	1,574,700	0.25	ICT impact study p. 97[ii]
Regular signage display only integrated in means of transport: passenger TV (airport/train/metro)	55	83	5,172,400	4.29	ICT impact study p. 97[ii]
Special signage display	110	333	13,432	0.04	ICT impact study + updates[i]

[i] Stock updated based on share of monitor by type used in VHK and Viegand Maagøe for the European Commission. 2020. ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT. [online] European Commission - Energy, p.77. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021]; which are 2014 forecasts for 2020, and based on updated estimations for EU28 based on IDC worldwide shipments between 2012 and 2020.

[ii] VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.77. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

70 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.88. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

71 Base-impacts.ademe.fr. 2021. *Base Impacts® - Documentation - folder 1.2.AE – "Référentiels secotriels & Echelles" - "Equipment électrique et électronique".* [online] Available at: <https://www.base-impacts.ademe.fr/gestdoclist> [Accessed 30 September 2021].

72 Club Green IT. 2021. *GreenIT.fr Benchmark 2021 (professionals).* [online] Available at: <https://club.greenit.fr/benchmark2021.html> [Accessed 30 September 2021].

Lately, a new technology has emerged: OLED screens are now considered the state-of-the-art. The environmental impacts are different from classic LCD TV.

Repartition is not known for monitors, but based on TV data, in 2019, 1.4% of sold TV worldwide were OLED, 2.7% were QLED, and 95.9% were LCD[73].

Energy consumption:

A study from ADEME[74] present a calculation of the electricity consumption of displays based on the screen size. It is based on 58 product references, and provide a formula to calculate the energy consumption of any screen size of display:

Extract from ADEME. J. Lhotellier, E. Lees, E. Bossanne, S. Pesnel. Mars 2018. *Modélisation et évaluation ACV de produits de consommation et biens d'équipements – Rapport.*

(see Figure 7 below)

For example, here are a few calculations:

Table 77 - Power use in relation to display size
Examples from a study from the French environmental agency ADEME

Screen size (inch)	Active mode power consumption (W)	Energy consumption (kWh/year)
30	31.3	173
40	52.3	288
50	77.8	428
60	107.6	591
70	141.6	777

Frequency of use: There is no data on frequency, mainly due to the variety of equipment. By hypothesis, it is considered that those monitors are mainly used during the day (6 AM to 9 PM), so in active mode 15h/day, and in stand-by mode 9h/day.

Typical lifespan: No specific information was available. By hypothesis, we used the same lifespan as regular monitor, which is 6 years without reuse and 7 years with reuse based on the GreenIT.fr professional benchmark.[75]

Penetration rate: No information on penetration rate

Figure 7 - Power use in relation to display size, an example from a study from the French environmental agency ADEME

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73 TrendForce, WitsView and Statista, 2020. *Global TV market share by type 2020 | TrendForce; WitsView; Statista.* [online] Statista. Available at: <https://www.statista.com/statistics/818389/world-tv-market-share-by-type/> [Accessed 30 September 2021].

74 ADEME, Lhotellier, J., Lees, E., Bossanne, E. and Pesnel, S., 2018. *Modélisation et évaluation ACV de produits de consommation et biens d'équipements – Rapport.* [online] ADEME. Available at: <https://librairie.ademe.fr/dechets-economie-circulaire/1189-modelisation-et-evaluation-des-impacts-environnementaux-de-produits-de-consommation-et-biens-d-equipement.html> [Accessed 30 September 2021].

75 Club Green IT. 2021. *GreenIT.fr Benchmark 2021 (professionals).* [online] Available at: <https://club.greenit.fr/benchmark2021.html> [Accessed 30 September 2021].

Characteristics: the special monitor model is a weighted mix of five configurations, with the following characteristics (see Table 78 below).

3.1.5.8.4. TVs

Number of units in 2019:

We applied the same method than the ICT impact study: the number of units and the average surface diagonal (in inch) and area (in dm²) allows us to estimate the total screen area, expressed in km² (see Table 79 below).

Lately, a new technology has emerged: OLED screens are now considered the state-of-the-art. The environmental impacts are different from classic LCD TV.

Table 78 - Other monitors characteristics

Configuration	Special monitors	Regular signage display - Exc. Integrated in means of transport	Regular signage display only integrated in means of transport: Traffic info & advertising display	Regular signage display only integrated in means of transport: passenger TV (airport/train/metro)	Special signage display
Repartition (based on ICT impact study*)	17,99%	63,48%	4,32%	14,18%	0,04%
Device weight (kg)	4,02	19,8	4,02	19,8	78,7
Display size (inches)	24	55	24	55	110
Display technology	LCD	LCD	LCD	LCD	LCD

* VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.77. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

Table 79 - TVs number of units

	Surface diag. Inch	Surface area dm²	Stock units in 2019	Total area in km²	Note
Household TV	44	53	216,077,800	115.33	International Video Federation, 2020[i]
Hospitality TV (hostels rooms, hospitals rooms)	40	44	9,436,472	4.16	Eurostat[ii]

[i] Two sources with completely different results were identified: (1) Source: International Video Federation, Total Europe: https://www.ivf-video.org/market-information (data 2019 published in 2020) => Europe share is not EU27 or EU28 but include 23 countries (19 from the EU + Iceland, Norway, Switzerland, Russia). First source estimates to 266,700,000 units the number of TV households. (2) Source: ICT impact study p.77, based on EIA stock 2020, but published in 2014. This figure, which is old, estimates to 477,000,000 units the number of TV households. As a result, since none of these two sources were perfectly fitting the scope, but in different manners ((1) geographical boundary vs (2) temporal boundary), we used as a basis the first source, which is the most recent one, and calculated on the basis of the population considered in the same source (633.3 million), an average number of TV per inhabitant of 0.42, which was used to estimate the number of TV households related to the EU28 population (Eurostat 2019 data), giving a final figure of 216,077,800. No other data was found. The absence of other sources to estimate the robustness of the data, and the high differences between the two sources figures, brings a very high level of uncertainty to the final figure.

[ii] The methodology used in the ICT impact study was kept, but sources used to estimate the number of hospital beds and hostel rooms were updated with the following Eurostat sources: (a) Number of curative beds in EU28 per 100,000 hab, (year 2018 used as a proxy), multiplied by Eurostat 2019 EU28 pop divided per 100,000 hab. (b) https://ec.europa.eu/eurostat/databrowser/view/tour_cap_nat/default/table?lang=en Year 2019, EU28, Number of bedrooms, Hostels and similar accommodation. No other data was found. The absence of other sources to estimate the robustness of the data gives a high level of uncertainty to the figure.

In 2019, 1.4% of sold TV worldwide were OLED, 2.7% were QLED, and 95.9% were LCD[76].

Energy consumption: an average of 179 kWh/year/device, based on ICT impact study.[77]

Frequency of use: 3.65 hours/day. VAUNET[78] estimates to 3.65 hours TV viewing time in the EU for 2019, which is both a consistent and geographically sound measurement. Both the ADEME and the ICT impact study uses a 4h/day viewing time (on-mode) for TV, which is not far. The ICT impact study indicates 10h/day in stand-by mode for TV. The VAUNET estimates brings a correct level of certainty to the figure, but a better level of certainty would need complementary surveys.

The frequency of use we used is therefore 3.65h/day in active mode, 8h/day in stand-by mode, and 12.35h/day in off mode, based on a mix between the French labelling scheme[79] and the VAUNET survey for the EU.

Typical lifespan: 6 years without reuse and 7 years with reuse based on the GreenIT.fr professional benchmark[80], 8 years based on ADEME report[81].

Penetration rate: No information on penetration rate

Characteristics: the TV model separated between the personal and professional configuration.

For the personal configuration, it is a weighted mix of two configurations, with the following characteristics:

Table 80 - Personal TVs characteristics

Configuration	LCD LED	OLED
Repartition (based on Statista data*)	98.6%	1.4%
Device weight (kg)	9.35	29.1
Display size (inches)	45	68
Display technology	LCD LED	OLED
PWB surface (cm^2)	5,674	13,284

* TrendForce, WitsView and Statista, 2020. *Global TV market share by type 2020 | TrendForce; WitsView; Statista.* [online] Statista. Available at: <https://www.statista.com/statistics/818389/world-tv-market-share-by-type/> [Accessed 30 September 2021].

For the professional configuration, it is a weighted mix of two configurations, with the following characteristics:

Table 81 - Professional TVs characteristics

Configuration	LCD LED	OLED
Repartition (based on Statista data*)	98.6%	1.4%
Device weight (kg)	9.15	29.1
Display size (inches)	40	68
Display technology	LCD LED	OLED
PWB surface (cm^2)	4,354	13,284

* TrendForce, WitsView and Statista, 2020. *Global TV market share by type 2020 | TrendForce; WitsView; Statista.* [online] Statista. Available at: <https://www.statista.com/statistics/818389/world-tv-market-share-by-type/> [Accessed 30 September 2021].

76 TrendForce, WitsView and Statista, 2020. *Global TV market share by type 2020 | TrendForce; WitsView; Statista.* [online] Statista. Available at: <https://www.statista.com/statistics/818389/world-tv-market-share-by-type/> [Accessed 30 September 2021].

77 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.88. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

78 VAU.NET. 2021. *Fernsehnutzung in Europa auch 2019 auf hohem Niveau | VAU.NET.* [online] Available at: <https://www.vau.net/tv-nutzung/content/fernsehnutzung-europa-2019-hohem-niveau> [Accessed 30 September 2021].

79 Base-impacts.ademe.fr. 2021. *Base Impacts® - Documentation - folder 1.2. AE – "Référentiels secotriels & Echelles" - "Equipment électrique et électronique".* [online] Available at: <https://www.base-impacts.ademe.fr/gestdoclist> [Accessed 30 September 2021].

80 Club Green IT. 2021. *GreenIT.fr Benchmark 2021 (professionals).* [online] Available at: <https://club.greenit.fr/benchmark2021.html> [Accessed 30 September 2021].

81 Base-impacts.ademe.fr. 2021. *Base Impacts® - Documentation - folder 1.2. AE – "Référentiels secotriels & Echelles" - "Equipment électrique et électronique".* [online] Available at: <https://www.base-impacts.ademe.fr/gestdoclist> [Accessed 30 September 2021].

3.1.5.8.5. Summary for electronic displays (excl. TVs)

Table 82 - Summary of electronic displays excluding TVs

	Surface diag. Inch	Surface area dm²	Stock units	Total area in km²
Regular monitors	24	16	54,397,952	8.64
Special monitors	24	16	5,708,427	0.91
Regular signage display - Exc. Integrated in means of transport	55	83	20,147,390	16.81
Regular signage display only integrated in means of transport: Traffic info & advertising display	24	16	1,574,700	0.25
Regular signage display only integrated in means of transport: passenger TV (airport/train/metro)	55	83	5,172,400	4.29
Special signage display	110	333	13,432	0.04
			Total area	**30.94**

3.1.5.8.6. Summary for electronic displays (incl. TVs)

Table 83 - Summary of electronic displays including TVs

	Surface diag. Inch	Surface area dm²	Stock units	Total area in km²
Regular monitors	24	16	54,397,952	8.64
Special monitors	24	16	5,708,427	0.91
Regular signage display - Exc. Integrated in means of transport	55	83	20,147,390	12.26
Regular signage display only integrated in means of transport: Traffic info & advertising display	24	16	1,574,700	0.25
Regular signage display only integrated in means of transport: passenger TV (airport/train/metro)	55	83	5,172,400	4.29
Special signage display	110	333	13,432	0.04
TVs - Household	44	53	216,077,800	115.33
TVs – Hospitality (hostels, hospitals)	40	44	9,436,472	4.16
			Total area	**150.44**

3.1.5.9. TV box

Definition: An end-user specific box set used to decode TV signals, near the TV. In can be from cable, IPTV, terrestrial of satellite.

Number of units in Europe in 2019: 208,328,200 TV box units.

181,000,000 households were equipped by either IPTV (26,000,000 households), cable (50,000,000 households), satellite (57,000,000 households) or Terrestrial (48,000,000 households) in the EU-27, based on the ICT impact study.[82]

We extrapolated to include the UK, based on the number of households in the EU-27 and in the EU-28 in 2019 given by Eurostat[83], which gives the figures below:

Table 84 - TV boxes number of units

	EU27	EU28 extrapolation
IPTV	26,000,000	29,925,600
Satellite	57,000,000	65,606,100
Cable	50,000,000	57,549,200
Terrestrial	48,000,000	55,247,300
TV Box	181,000,000	208,328,200

Note: LCI data were only available on IPTV boxes. We decided to consider all boxes to have the same impact in order not to neglect important source of impact.

Energy consumption: Energy consumption: 73 kWh/year/device in 2020. The energy consumption of TV boxes is based on in the ICT impact study 2020.[84]

Frequency of use: the frequency of use is considered the same as TV, as their use is simultaneous.

No other data was found. The absence of dedicated sources to estimate the robustness of the data gives some uncertainty to the figure which is based on TVs frequency of use. The frequency of use we used is therefore 3.65h/day in active mode, 8h/day in stand-by mode, and 12.35h/day in off mode, based on a mix between the French labelling scheme[85] and the VAUNET survey for the EU.

Typical lifespan: No information on lifetime was available. A lifetime of 5 years was chosen by hypothesis.

Penetration rate: No information on penetration rate

Characteristics: the TV box model is a single configuration, with the following characteristics:

Table 85 - TV box characteristics

	TV box
Repartition (by hypothesis)	100%
Device weight (kg)	0.99
SSD capacity (GB)	240

3.1.5.10. Game consoles

Definition: According to the SRI[86], quoted in the ICT impact study "Games Console is a computing device whose primary function is to play video games. Games Consoles share many of the hardware architecture features and components found in general personal computers (e.g. central processing unit(s), system memory, video architecture, optical drives and/or hard drives or other forms of internal memory). Games Consoles covered by this SRI are those that:

- Utilise either dedicated handheld or other interactive controllers designed to enable game playing (rather than the mouse and keyboard used by personal computers); and
- are equipped with audio-visual outputs for use with external televisions as the primary display; and
- use dedicated Console operating systems (rather than using a conventional PC operating system); and
- may include other secondary features such as optical disc player, digital video and picture viewing, digital music playback, etc.; and

82 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.49. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

83 Eurostat. 2021. *Number of private households by household composition, number of children and age of youngest child | Eurostat.* [online] Available at: <https://ec.europa.eu/eurostat/databrowser/view/lfst_hhnhtych/default/table?lang=en> [Accessed 30 September 2021].

84 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.115. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021]. Viegand Maagøe. 2018. Internal modelling files that supports the computer regulation.

85 Base-impacts.ademe.fr. 2021. *Base Impacts® - Documentation - folder 1.2. AE – "Référentiels secotriels & Echelles" - "Equipment électrique et électronique".* [online] Available at: <https://www.base-impacts.ademe.fr/gestdoclist> [Accessed 30 September 2021].

86 In the EU, video games consoles are subject to a Self-Regulatory Initiative (SRI) under the Eco-design Directive (ENTR lot 3). Signatories are the three main producers: Microsoft (Xbox), Sony (PlayStation) and Nintendo. The most recent version is SRI 2.6.3 (2018) and the latest compliance report by the Independent Inspector (Intertek) was released in October 2019 (Intertek, Independent Inspector Annual Compliance Report – Games Consoles Self-Regulatory Initiative, Reporting Period 2018, Oct. 2019). All information on the SRI is available on a dedicated website www.efficientgaming.eu.

- are mains powered devices that use more than 20 watts in Active Game mode with either Sales stock."[87]

Number of units in Europe in 2019: 141,740,564 units. The stock of game console has been calculated using annual sales between 2014 and 2020 reported by VGChartZ for Europe (continent)[88], and based on the average lifespan of 6,5 years for game consoles.

The consoles considered were the following:

Table 86 - Consoles number of units

Model	Type	Number
PSP	portable	134,268
Wii	desktop	158,643
X360	desktop	673,286
PS3	desktop	2,184,059
3DS	portable	13,427,462
PSV	portable	2,410,259
WiiU	portable	1,791,061
PS4	desktop	69,183,431
XOne	desktop	13,146,494
NS	portable	33,967,168
PS5	desktop	2,855,628
XS	desktop	1,808,806
Total portable consoles		**51,730,218**
Total desktop consoles		**90,010,347**
Total		**141,740,564**

Energy consumption: 55.88 kWh/year/desktop game console and 5.15 kWh/year/mobile game console in 2020. The energy consumption of consoles is based on in the ICT impact study 2020[89], adapted to the numbers from VGChartZ above, and using the Global Web Index Q3 figures presented by Hootsuite and reported in the ICT impact study[90] as seen below in "Frequency of use".

Table 87 - Consoles electricity consumption

Model	Type	Number	Consumption (kWh/year)
PSP	portable	134,268	Unknown
Wii	desktop	158,643	Unknown
X360	desktop	673,286	Unknown
PS3	desktop	2,184,059	Unknown
3DS	portable	13,427,462	Unknown
PSV	portable	2,410,259	Unknown
WiiU	portable	1,791,061	Unknown
PS4	desktop	69,183,431	44.21
XOne	desktop	13,146,494	116.58
NS	portable	33,967,168	5.15
PS5	desktop	2,855,628	Unknown
XS	desktop	1,808,806	60.67
Average portable consoles			**5.15**
Average desktop consoles			**55.88**

Frequency of use: between 42 minutes and 56 minutes daily depending on the country, based on Global Web Index Q3 figures presented by Hootsuite and reported in the ICT impact study[91] as below:

Table 88 - Consoles frequency of use per countries

Countries	Games console daily usage
Germany	0h42m
Netherlands	0h42m
Poland	0h43m
Italy	0h49m
Spain	0h54m
France	0h56m
Average, weighted by population	**0h48m**

Typical lifespan: The typical average lifespan of game consoles is estimated to 6,5 years based on gaming sector industrial knowledge from the authors. There is a good level of certainty of this figure.

Characteristics: the desktop model separated between the desktop and mobile configuration.

87 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.108. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

88 VGChartz. 2021. *Yearly Hardware Comparisons - Europe - VGChartz.* [online] Available at: <https://www.vgchartz.com/tools/hw_date.php?reg=Europe&ending=Yearly> [Accessed 30 September 2021].

89 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.91. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021]; Maagøe, V., 2018. Internal modelling files that supports the computer regulation.

90 *Ibid*, p.239.

91 *Ibid*, p.239.

For the desktop configuration, it is a weighted mix of four configurations, with the following characteristics.

Table 89 - Desktop consoles characteristics

Configuration	Playstation 4	Playstation 5	Xbox One S	Xbox One
Repartition (based on VGChartZ*)	79.5%	3.3%	2.1%	15.1%
Device weight (kg)	2.8	4.78	2.9	3.5
PWB surface (cm²)	838,75		904,72	
Processor	AMD Jaguar	AMD Zen 2	AMD Jaguar	AMD Jaguar
RAM (GB)	8	16	8	8
Graphic card	AMD Radeon	AMD RDNA 2	AMD Radeon	AMD Radeon
SSD capacity (GB)	0	825	0	0
HDD capacity (GB)	500	0	500	500

* VGChartz. 2021. *Yearly Hardware Comparisons - Europe - VGChartz.* [online] Available at: <https://www.vgchartz.com/tools/hw_date.php?reg=Europe&ending=Yearly> [Accessed 30 September 2021].

For the mobile configuration, it is a weighted mix of two configurations, with the following characteristics:

Table 90 - Portable consoles characteristics

Configuration	Nintendo Switch	Nintendo Switch lite
Repartition (by hypothesis)	50%	50%
Device weight (kg)	0.297	0.277
Display size (inches)	6.2	5.5
Display technology	Tactile LCD	Tactile LCD
PWB surface (cm²)	Nvidia Tegra 20nm	Nvidia Tegra 16nm
Processor	4	4
RAM (GB)	32	32
SSD capacity (GB)	189.49	189.49
PWH size (cm²)	6.2	5.5

3.1.5.11. Printers

Definition: The product group of imaging equipment considered here are the following:

Table 91 - Printers categories

Product	Description*
Mono laser MFD	A multi-functional printer, that can copy, scan and print, that use laser marking technology (sometime referred to as electro-photographic) to print in one colour only.
Colour laser MFD	A multi-functional printer, that can copy, scan and print, that use laser marking technology (sometime referred to as electro-photographic) to print in multiple colours.
Mono laser printer	A printer that uses laser marking technology (sometime referred to as electro-photographic) to print in one colour only.
Colour laser printer	A printer that uses laser marking technology (sometime referred to as electro-photographic) to print in multiple colours.
Mono laser copier	A commercially available imaging product whose sole function is the production of hard copy duplicates from graphic hard copy originals, in one colour only.
Colour laser copier	A commercially available imaging product whose sole function is the production of hard copy duplicates from graphic hard copy originals, in multiple colours.
Ink jet MFD	A multi-functional printer, that can copy, scan and print, that uses Inkjet marking technology to print in several colours.
Ink jet printer	A printer that uses inkjet marking technology to print in multiple colours.
Professional printers/MFD	A professional printer or MFD that supports a basis weight greater than 141g/m2; A3 capable; if it only prints monochrome the IPM is equal or greater than 86; if it prints in colour the IPM is equal or greater than 50; print resolution of 600x600 dpi or greater; weight of the base model greater than 180 kg and several other features such as hole punch and ring binding.
Scanner	A product whose primary function is to convert paper originals into electronic images that can be stored, edited converted or transmitted.

* Definition from: VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.123. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

Note: The ICT impact study also provides some information about Fax machine and 3D printers, that we have excluded from our scope for 3 reasons: first, they are at the edge of the scope of what could be considered or not as ICT; second, there represent either a limited stock of the equipment (270,000 3D printers) or limited impacts *(faxes), third, there was not enough information about these devices to include them in our scope.*

Number of units in Europe in 2019: Based on the stock of equipment reported the ICT impact study for the EU-28, and interpolated to obtain 2019, as below:

Table 92 - Printers number of units

Product	Number of units in 2019	Category
Mono laser MFD	12,186,500	Office printer
Colour laser MFD	12,160,500	Office printer
Mono laser printer	10,156,500	Personal printer
Colour laser printer	9,578,000	Personal printer
Mono laser copier	878,500	Office printer
Colour laser copier	1,435,000	Office printer
Ink jet MFD	70,882,000	Personal printer
Ink jet printer	5,281,000	Personal printer
Professional printers/MFD	1,486,500	Professional printer/MFD
Scanner	3,623,200	Personal printer
Total	**127,667,700**	

Note: *LCI data were only available on the following printers: mono laser MFD, colour laser MFD and professional printers / MFD. Other printers have been extrapolated, with the following distinction: personal printer, based on based on mono laser MFD and colour laser MFD; office printer, based on mono laser MFD and colour laser MFD; professional printer / MDF.*

Energy consumption: 5.55 TWh/year of annual electricity consumption of the EU-28 stock for 2019, based on the data of the ICT impact study,[92] as below:

Table 93 - Printers electricity consumption

Product	Annual elec. Consumption [expressed in TWh/ year for the stock]	Annual elec. Consumption [expressed in kWh/ year per device]
Mono laser MFD	0.96	79
Colour laser MFD	1.12	92
Mono laser printer	0.72	71
Colour laser printer	1.05	110
Mono laser copier	0.07	79
Colour laser copier	0.13	92
Ink jet MFD	0.43	6
Ink jet printer	0.01	2
Professional printers / MFD	0.99	664
Scanner	0.07	19
Annual elec. consumption of the stock	**5.55**	

Frequency of use: No data were found regarding frequency of use printers.

Typical lifespan: Based on the ICT impact study[93], the typical lifespan of printers is of 6 years for Mono laser MFD, Colour laser MFD, Mono laser printer, Colour laser printer, Mono laser copier, Colour laser copier, and Scanner. It is of 5 years for ink jet printers and ink jet MFD. This lifespan is consistent with the lifespan used by the ADEME. No data were found for professional printers / MFD. Since no data was found on the lifespan of professional printers a default lifespan of 6 years was applied by the authors, based on the lifespan of the other categories of printers. The absence of other sources to estimate the robustness of the data gives some uncertainty to the figure. This leads to a small uncertainty in the impacts of professional printers in the printers' sub-category of user equipment, which has a very limited impact on the overall study results since printers accounts for only a small part of the impacts.

Penetration rate: No data were found regarding the penetration rate of printers.

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92 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.127. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

93 *Ibid*, p.124.

3.1.5.12. External SSD & HDD, USB keys

Definition: External hard drives equipment used to store and retrieve data when connected to a computer. There are 2 types of external hard drives technologies: HDDs (Hard Disk Drive) and SSD (Solid-State Drive). Looking at the appearance of external hard drives, 3 categories can be defined as below:

- An HDD is an electro-mechanical data storage device uses magnetic storage and one or more rigid rapidly rotating platters coated with magnetic material. HDD storage devices are fragile.
- An SSD uses integrated circuit assemblies to store data in semiconductor cells. There are smaller and less fragile than HDD devices.
- A USB key, or memory-based USB drive, or USB flash drive uses integrated circuit assemblies to store data in semiconductor cells like SSD, but with lower capacities. A USB key is much smaller than HDD and SSD devices.

HDDs are progressively replaced by SDDs, that are less sensible to physical shocks, run silently, have quicker access time and lower latency.

Number of units in Europe in 2019:

- HDD and SSD: Based on private reports of Omdia and Grand View Research, we extrapolated EU market figures to the EU-28. Another source from the IDC was found at a global level, but as it included also HDD and SSD drives used in data centres, it was estimated too uncertain to be used. The absence of other sources to estimate the robustness of the data gives a high-level uncertainty to the figure.

Table 94 - HDD and SSD number of units

	HDD [number of units]	SSD [number of units]
EU28 stock in 2019	32,515,000	7,031,100

- USB keys: An IPSOS study[94] indicates an average of 2.2 USB key per household in France. Considering the same ratio for European households (266,700,000 households), the total number is 586,740,000 USB keys. No other source was found. The absence of other sources to estimate the robustness of the data gives a high-level of uncertainty to the figure, which accounts for only a marginal part of the overall impacts of user equipment considering the very small size of USB keys.

Energy consumption:

- SSD: 0.6 to 2.8 W, weighted based on Buildcomputers.net information.[95]
- HDD: 0.7 to 9 W, weighted based on Buildcomputers.net information (2.5” HDD: 0.7 to 3 W; 3.5” HDD: 6.5 to 9 W)[96]
- USB key: 0.6 W in read mode and 2.5 W in write mode (Authors’ estimations).

Frequency of use: No data were found regarding frequency of use of SSD, HDD and USB keys. By hypothesis, we considered 10 min of use per day, considering 50% in read mode, and 50% in write mode.

Typical lifespan: No data were found regarding typical lifespan of SSD & HDD. In the absence of precise data, a default lifespan of 5 years was applied for SSD & HDD, based on the average lifespan of professional equipment.

Penetration rate: No data were found regarding penetration rate of SSD & HDD.

Characteristics:

- **HDD:** the HDD model is a weighted mix of three configurations, with the following characteristics:

Table 95 - HDD characteristics

Configuration	Small capacity	Mid-range capacity	High capacity
Repartition (by hypothesis)	50%	40%	10%
Device weight (kg)	0.17	0.149	0.238
Capacity (GB)	1000	2000	4000

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94 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.114. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

95 buildcomputers.net. n.d. *SSD vs HDD - Is a Solid State Drive or Hard Disk Drive Better?.* [online] Available at: <https://www.buildcomputers.net/ssd-vs-hdd.html> [Accessed 30 September 2021].

96 *Ibid.*

SSD: the SSD model is a weighted mix of three configurations, with the following characteristics:

Table 96 - SSD characteristics

Configuration	Small capacity	Mid-range capacity	High capacity
Repartition (by hypothesis)	50%	40%	10%
Device weight (kg)	0.5	0.13	0.52
Capacity (GB)	512	1024	2048
Technology	TLC	TLC	TLC

USB keys: the USB key is a weighted mix of three configurations, with the following characteristics:

Table 97 – USB keys characteristics

Configuration	Small capacity	Mid-range capacity	High capacity
Repartition (by hypothesis)	10%	60%	30%
Device weight (kg)	0.015	0.0091	0.01
Capacity (GB)	16	32	128
Technology	TLC	TLC	TLC

3.1.5.13. Connected speakers

Definition: A connected speaker or smart speaker is a type of speaker and voice command device. It integrates a virtual assistant offering voice activation and interaction through the use of key words. Connected speakers rely on Wi-Fi, Bluetooth, and other protocol standards to propose interactions such as to home automation devices, or the Internet.

Number of units in Europe in 2019: 42,691,700 units. Based on the forecast of smart speakers' sales worldwide by region in 2019, published by Statista from a survey of Futuresource[97], and an average lifespan of 5 year (default), the number of connected speakers is estimated to 50,000,000 units in Europe. This estimation is subjected to a high level of uncertainty in the absence of more complete data to estimate the stock in the EU-28 or to estimate the shipments of connected speakers in the previous years. Based on another source (Canalys, 2021)[98], and on an average lifespan of 5 years (default), the number of connected speakers is estimated to a stock of 245,000,000 smart speakers. Based on a weighted factor between EU-28 GDP and inhabitants in 2019, the stock of connected speakers in the EU-28 is estimated around 42,691,700 units. This estimation is still subjected to an important level of uncertainty in the absence of more complete data to estimate more precisely the stock in the EU-28.

Energy consumption: A Citizing report[99] indicates an annual global consumption of 0.66 TWh for 28,700,000 devices, so a 23 kWh per year per device consumption.

Frequency of use: The Citizing report[100] indicates 4 hours per day in on-mode, and 20 hours per day in standby mode.

Typical lifespan: In the absence of precise data, a default lifespan of 5 years was applied for connected speakers.

Penetration rate: No data were found regarding penetration rate of connected speakers.

Characteristics: the connected speaker model is a single configuration, with the following characteristics:

Table 98 - Connected speakers characteristics

Configuration	Connected speaker
Repartition (by hypothesis)	100%
Device weight (kg)	0.838

3.1.5.14. IoT connected objects

Description: "Objects that become internet-enabled (IoT devices) typically interact via embedded systems, some form of network communications, as well as combination of edge and cloud computing. The data from IoT connected devices is often (but not exclusively) used to create novel end-user applications."[101]

Computers, tablets, or smartphones are not considered IoT. RFID can be considered as extremely simplified and early example of IoT, but this is subject to discussion; in this LCA study, we excluded RFID from our scope.

97 Canalys, 2021. *Smart speaker shipments worldwide by vendor 2020 | Canalys; Statista estimates.* [online] Statista. Available at: <https://www.statista.com/statistics/796349/worldwide-smart-speaker-shipment-by-vendor/> [Accessed 30 September 2021]; Canalys, 2021. Smart Speaker Analysis. [online] Canalys. Available at: <https://www.canalys.com/analysis/smart+speaker+analysis> [Accessed 30 September 2021].

98 *Ibid.*

99 Citizing, 2020. *Empreinte carbone du numérique en France.* [online] Sénat. Available at: <http://www.senat.fr/fileadmin/Fichiers/Images/commission/Developpement_durable/MI_empreinte_environnementale/r19-555-annexe.pdf> [Accessed 30 September 2021].

100 *Ibid.*

101 Definition of the IoT developed by IoT Analytics: IoT Analytics. 2021. Our Coverage. [online] Available at: <https://iot-analytics.com/our-coverage/> [Accessed 30 September 2021].

IoT devices categories

We based our IoT devices inventory on the IEA 2019 report[102] to obtain the following categories and sub-categories:

Table 99 - IoT sub categories

Sector	Category - Group - Device
	Security - Video
Residential	Security - Video
Business/Public	Security - Video
Residential	Security - Control
Residential	Automation - Water Heating
Public	Automation - Street Lights
Residential	Automation - Space Conditioning
Residential	Automation - Space Conditioning - Smart Thermostat
Residential	Automation - Space Conditioning - Air Conditioners
Residential	Automation - Lightning
Residential	Automation - Lightning - Wi-Fi
Residential	Automation - Lightning - LE
Residential	Automation - Cooking
Residential	Automation - Cooking - Oven + Cooktop
Residential	Automation - Cooking - Range Hood
Residential	Automation - Audio
Residential	Automation - Appliances
Residential	Automation - Appliances - Refrigerator
Residential	Automation - Appliances - Freezer
Residential	Automation - Appliances - Washing Machine
Residential	Automation - Appliances - Cloth Dryer
Residential	Automation - Appliances - Dishwasher
Residential	Automation - Appliances - Small Appliance
Residential	Automation - IoT
Public Utilities	Smart Meters
Residential	Sensors: Res - Wi-Fi
Residential	Sensors: Res - LE
Business	Sensors: Industry - LE
Public Health	Sensors: Health - LE
Business	Gateway: Bus
Residential	Gateway: LE to Wi-Fi
Business	Comm Building Control
Residential	Blinds + Windows

Number of IoT devices in EU-28

We estimated the number of IoT devices for the EU-28 based on the number of units worldwide in 2020 provided by the IEA 2019 report[103] and the Data Bridge Market Research report[104], considering that in 2019, Europe was responsible for 23% of global IoT spending According to IDC's Worldwide Internet of Things Spending Guide"[105]. But this report considers Europe market at a large scale, including Russia & Turkey for e.g. Thus, we used another calculation method based on world and EU-28 GDP in 2019. Based on this approach, the EU-28 market was estimated to 17.85 % of the worldwide IoT market (see table 100 next page).

This leads to a high level of uncertainty on the overall number of IoT devices estimated for the EU as no more precise regional data was found. However, these numbers seem consistent with ICT experts' knowledge, based on the fact that a wide range of various IoT connected devices are considered in this scope. Some can argue whether a such wide range of IoT device can be or not considered in the scope of ICT. Indeed, some of the devices considered here (for example, smart water heating, or smart refrigerators), are not ICT devices in their principal use, but know enters in the IoT category when they have a communication module (only the communication module is assessed). In this study, only the connected part of those devices is considered in the environmental footprint of ICT. Some could argue that the connected module is sometimes not even used, however there is currently not enough information to estimate which proportion of the devices are concerned or not, and how long it represents during the overall device lifespan. Moreover, this raises the following question: "which sector has to consider the impact of appliances that are manufactured with an IoT complement, but is sold "IoT disabled"?"

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102 IEA, 2019. *Total Energy Model for Connected Devices,. IEA 4E EDNA*. [online] pp.33-34, 53-60, 62-68. Available at: <https://www.iea-4e.org/wp-content/uploads/publications/2019/06/A2b_-_EDNA_TEM_Report_V1.0.pdf> [Accessed 30 September 2021].

103 *Ibid*, p.53-60.

104 Data Brigde Market Research, 2020. *Global Industrial IoT Market - Industry Trends and Forecast to 2027.* [online] Available at: <https://www.databridgemarketresearch.com/reports/global-industrial-iot-market> [Accessed 30 September 2021].

105 CBI.eu. 2021. *The European market potential for (Industrial) Internet of Things | CBI.* [online] Available at: <https://www.cbi.eu/market-information/outsourcing-itobpo/industrial-internet-things/market-potential> [Accessed 30 September 2021].

As the number of IoT equipment is quickly growing, more precise studies on the IoT must be conduct to estimate more accurately the impacts of these equipment.

Table 100 - IoT number of units

Category - Group - Device	Nb of Units EU28 (GDP extrapolation: 17.85%)	Nb of Units Worldwide in 2020
Security - Video	53,536,207	300,000,000
Security - Control	89,227,011	500,000,000
Automation - Water Heating	53,536,207	300,000,000
Automation - Street Lights	53,536,207	300,000,000
Automation - Space Conditioning	53,536,207	300,000,000
Automation - Lightning	142,763,218	800,000,000
Automation - Cooking	53,536,207	300,000,000
Automation - Audio	178,454,022	1,000,000,000
Automation - Appliances	71,381,609	400,000,000
Automation - IoT	1,124,260,342	6,300,000,000
Smart Meters	223,067,528	1,250,000,000
Sensors: Res - Wi-Fi	8,922,701	50,000,000
Sensors: Res - LE	46,398,046	260,000,000
Sensors: Industry - LE	80,304,310	450,000,000
Sensors: Health - LE	117,779,655	660,000,000
Gateway: Bus	9,814,971	55,000,000
Gateway: LE to Wi-Fi	8,922,701	50,000,000
Comm Building Control	624,589,079	3,500,000,000
Blinds + Windows	4,461,351	25,000,000

Energy Consumption of IoT devices & Average lifespan

The IoT devices energy consumption presented in the IEA 2019 report[106] was used, as below:

Table 101 - IoT electricity consumption and lifespan

Sector	Category - Group - Device	Consumption Network Active [W]	Consumption Network Standby [W]	Network Active [h]	Network Standby [h]	Average Lifespan [year]	Scope of energy consumption included in TEM
	Security - Video						All energy, assume to be in standby state
Residential	Security - Video	2	2	0	24	5	All energy, assume to be in standby state
Business/Public	Security - Video	8	8	24	0	10	All energy, assume in active network state
Residential	Security - Control	0.001	0.001	0	24	5	All energy, assume to be in standby state
Residential	Automation - Water Heating	2	2	0	24	12	Only network connection
Public	Automation - Street Lights	1.5	1.5	0	24	10	Only network connection is additional
Residential	Automation - Space Conditionning	1.77	1.77	0	24	12	
Residential	Automation - Space Conditionning - Smart Thermostat	1.77	1.77	0	24	12	All energy, assume to be in standby state
Residential	Automation - Space Conditionning - Air Conditioners	1.77	1.77	0	24	12	Only network connection
Residential	Automation - Lightning			0	24	7	Only network connection
Residential	Automation - Lightning - WiFi	2	2	0	24	7	Only network connection
Residential	Automation - Lightning - LE	0.44	0.44	0	24	7	Only network connection
Residential	Automation - Cooking						Only network connection
Residential	Automation - Cooking - Oven + Cooktop	2.5	2.5	0	24	15	Only network connection
Residential	Automation - Cooking - Range Hood	2.5	2.5	0	24	4	Only network connection
Residential	Automation - Audio	3.34	2.84	2	22	4	Always in listening mode (standby), some time in network active
Residential	Automation - Appliances						Only network connection
Residential	Automation - Appliances - Refrigerator	15	2.5	2	22	12	Only network connection
Residential	Automation - Appliances - Freezer	2.5	2.5	0	24	12	Only network connection
Residential	Automation - Appliances - Washing Machine	2.5	2.5	0	24	12	Only network connection
Residential	Automation - Appliances - Cloth Dryer	2.5	2.5	0	24	12	Only network connection
Residential	Automation - Appliances - Dishwasher	2.5	2.5	0	24	12	Only network connection
Residential	Automation - Appliances - Small Appliance	2.5	2.5	0	24	4	Only network connection
Residential	Automation - IoT						
Public Utilities	Smart Meters	2	2	0	24	12	Only network connection
Residential	Sensors: Res - WiFi	1.2	1.2	0	24	5	All energy, assume to be in standby state
Residential	Sensors: Res - LE	0.001	0.001	0	24	5	All energy, assume to be in standby state
Business	Sensors: Industry - LE	0.001	0.001	0	24	5	All energy, assume to be in standby state
Public Health	Sensors: Health - LE	0.001	0.001	0	24	5	All energy
Business	Gateway: Bus	7	7	24	0	7	All energy, network active
Residential	Gateway: LE to WiFi	1.4	1.4	24	0	7	All energy, network active
Business	Comm Building Control	1.5	1.5	0	24	12	All energy, assume to be in standby state
Residential	Blinds + Windows	0.0001	0.0001	0	24	5	Network energy only, assume to be in standby state

106 IEA, 2019. *Total Energy Model for Connected Devices,. IEA 4E EDNA.* [online] pp.33-34, 53-60, 62-68. Available at: <https://www.iea-4e.org/wp-content/uploads/publications/2019/06/A2b_-_EDNA_TEM_Report_V1.0.pdf> [Accessed 30 September 2021].

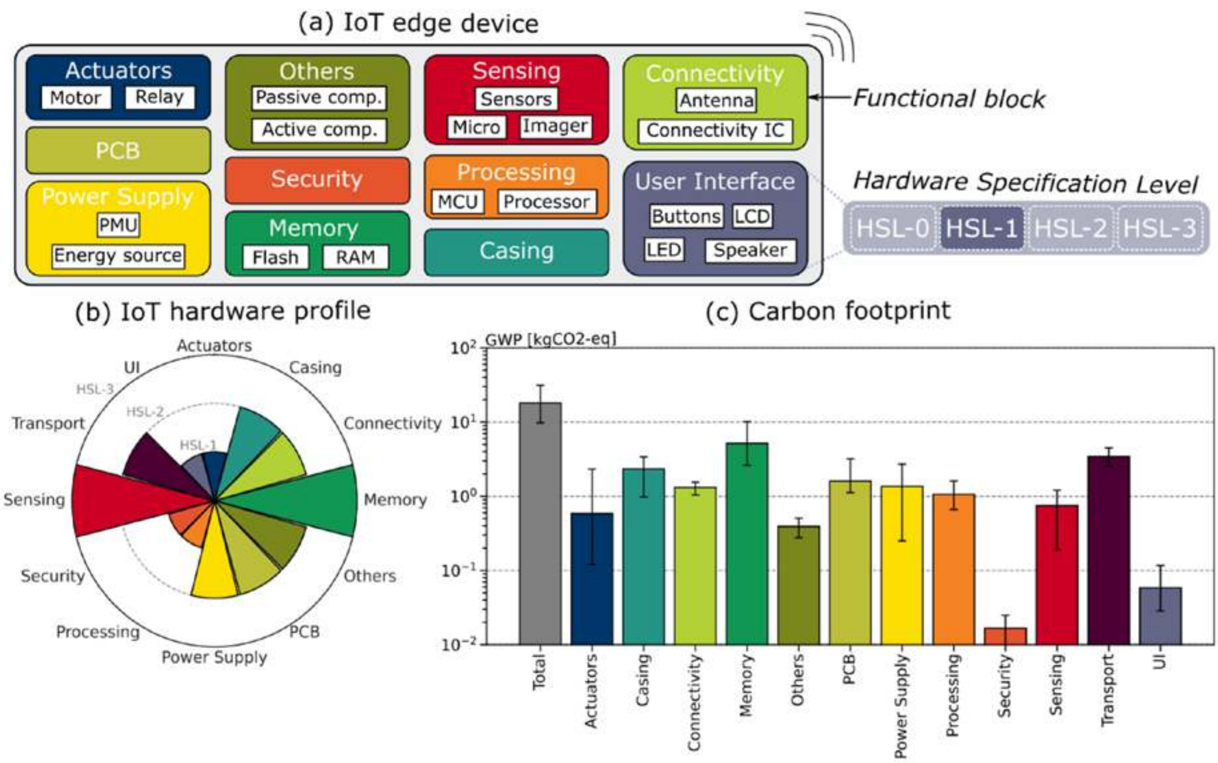
Penetration rate

Based on 2020 Eurostat data[107], as the penetration rate of IoT devices is estimated to 35% in the EU-27 and to 52% in the UK, we estimate EU-28 penetration devices of IoT use to 37.2% with the help of demographic indicators from the ONS UK[108] and Internet World Stats for the EU-27[109].

IoT hardware profiles

The IoT connected objects are characterised by their miscellaneous designs, making the performance of LCA for a specific connected object far from being representative of the variety of designs and applications in the IoT field. A recent Belgium study (submitted for review in 2021)[110] identified 12 functional blocks, with different functions and hardware specifications, that can be used for IoT connected objects modelling to obtain different IoT hardware profiles, as represented in Figure 22 below with 4 HSPs (Hardware Specification Levels, from 0 to 3):

Figure 8 - (a) The general architecture of an IoT edge device with the concept of functional blocks and hardware specification level, (b) an example of IoT hardware profile, (c) the resulting carbon footprint obtained by the framework for the hardware profile in (b).



Source: Pirson, T. and Bol, D., 2021. *Assessing the embodied carbon footprint of IoT edge devices with a bottom-up life-cycle approach*, p.3.[online] Available at: <https://www.semanticscholar.org/paper/Assessing-the-embodied-carbon-footprint-of-IoT-edge-Pirson-Bol/49ac45f5d59ac2047548fd168eff62393dfdd2ed> [Accessed 30 September 2021].

107 Eurostat. 2021. *Internet of Things - use*. [online] Available at: <https://ec.europa.eu/eurostat/databrowser/view/ISOC_IIOT_USE__custom_766794/default/table?lang=en> [Accessed 30 September 2021].

108 Ons.gov.uk. 2021. *Dataset - Internet users | Office for National Statistics*. [online] Available at: <https://www.ons.gov.uk/businessindustryandtrade/itandinternetindustry/datasets/internetusers> [Accessed 30 September 2021].

109 Internetworldstats.com. 2021. *European Union Internet Usage and Population Stats | Internet World Stats*. [online] Available at: <https://www.internetworldstats.com/europa.htm> [Accessed 30 September 2021].

110 Pirson, T. and Bol, D., 2021. *Assessing the embodied carbon footprint of IoT edge devices with a bottom-up life-cycle approach*. [online] Available at: <https://www.semanticscholar.org/paper/Assessing-the-embodied-carbon-footprint-of-IoT-edge-Pirson-Bol/49ac45f5d59ac2047548fd168eff62393dfdd2ed> [Accessed 30 September 2021].

Each hardware specification level of each functional block is related to a hardware profile that can be assessed. The hardware profiles are indicated in the table below:

Table 102 - IoT hardware specification profile assessment

Table 1: Detailed life-cycle inventory (LCI) for IoT hardware profiles. For each *Hardware Specification Level*, lower/typical/upper parameters considered are given.

Functional Block	Hardware Specification Level (HSL)			
	HSL-0	HSL-1	HSL-2	HSL-3
Actuators	No actuator	Vibration motor (1g) 1/2/4	Relay (SSR) 1/2/4	DC motor (50g) 1/4/6 Motor driver ‡ 1/2/5 mm^2 Motor driver transistor 1/4/6
Casing	No casing	ABS plastic granulate 10/50/100 g Aluminium 1/10/30 g Steel 1/10/30 g	ABS plastic granulate 200/400/500 g Aluminium 20/80/150 g Steel 20/80/150 g	ABS plastic granulate 700/800/900 g Aluminium 70/160/300 g Steel 70/160/300 g
Connectivity	Embedded in *Processing* (share of the die area) Printed antenna (embedded in *PCB*)	Connectivity IC * 5/10/20 mm^2 Printed antenna (embedded in *PCB*)	Connectivity IC ▲ 20/30/45 mm^2 External whip-like antenna 10/15/30 g	Connectivity IC ▲ 45/50/60 mm^2 External whip-like antenna 10/15/30 g
Memory	Embedded in *Processing*, Flash + RAM ($\simeq$ kB)	DRAM ◇ (32/128/512 MB) 2/7.9/31.5 mm^2 Flash † (32/128/512 MB) 0.2/0.8/3.2 mm^2	DRAM ◇ (0.5/1/2 GB) 31.5/61.5/123.1 mm^2 Flash † (1/4/8 GB) 6.3/25/50 mm^2	DRAM ◇ (0.5/1/2 GB) 31.5/61.5/123.1 mm^2 Flash † (8/16/32 GB) 50/100/200 mm^2
Others	Capacitors and resistors 5/10/15 Diodes 2/2/2, transistors 1/2/3 Tantalum capacitors 0/0/2, crystals 0/1/1	Capacitors and resistors 15/20/25 Diodes 2/4/6, transistors 2/4/6 Tantalum capacitors 0/0/3, crystals 1/1/2 Steel metal shield 0.5/1/2 g, cables 1/2/5 cm	Capacitors and resistors 40/50/60 Diodes 2/4/6, transistors 4/7/9 Tantalum capacitors 0/0/4, crystals 1/2/4 Steel metal shield 0.5/1/2 g , cables 1/2/5 cm	Capacitors and resistors 75/85/100 Diodes 2/6/10, transistors 7/10/15 Tantalum capacitors 0/2/4, crystals 1/2/4 Steel metal shield 0.5/1/2 g, cables 1/2/5 cm
PCB	FR4 (4 layers) 8/10/15 cm^2 Solder Paste (SAC305) 4/8/13 mg	FR4 (4 layers) 15/35/50 cm^2 Solder Paste (SAC305) 28/53/98 mg	FR4 (8 layers) 35/50/100 cm^2 Solder Paste (SAC305) 99/155/249 mg	FR4 (8 layers) 80/120/150 cm^2 Solder Paste (SAC305) 178/265/454 mg
Power Supply	Mains powered Power transistor 2/3/4 Diodes power 0/1/2, radial capacitor 2/3/4 Miniature coil 2/3/4, ring core coil 0/1/1 Power cable 0.5/1/1.5 m CEE 7/4 Schuko plug 0/1/1	1 Coin cell Li-Po/2 AAA alkaline/2 AA alkaline	Li-ion battery 10/50/100 g Power transistor 0/1/2 Diodes power 0/1/2, radial capacitor 0/1/2 Miniature coil 0/1/2	Li-ion battery 10/50/100 g Power transistor 0/1/2 Diodes power 0/1/2, radial capacitor 0/1/2 Miniature coil 0/1/2 External IC ‡ 5/15/25 mm^2
Processing	MCU * 5/10/17 mm^2	Application processor △ 20/30/45 mm^2 Auxiliary MCU * 5/10/17 mm^2	Application processor △ 50/60/75 mm^2 Auxiliary MCU * 5/10/17 mm^2	Application processor △ 75/100/125 mm^2 Auxiliary MCU * 5/10/17 mm^2
Security	Embedded in *Processing* or non-existent	External IC ‡ 1/2/3 mm^2	N/A	N/A
Sensing	No sensor	Electret microphone 0.05/0.1/0.2 g	Single-multiple sensors ° 0/3/5 mm^2	Single-multiple sensors ° 0/3/5 mm^2 Single CMOS imager ‡ (1/4" to 2/3") 8/30/58 mm^2
Transport	No transport	Transport from China to Europe Truck distance : 100/300/600 km Plane distance : 6100/6775/7400 km Total weight = 50/100/300 g	Transport from China to Europe Truck distance : 100/300/600 km Plane distance : 6100/6775/7400 km Total weight = 300/650/900 g	Transport from China to Europe Truck distance : 600/900/1200 km Plane distance : 6100/6775/7400 km Total weight = 900/1500/2000 g
User Interface	No user interface	Switch-button 0/1/2 LED 1/2/4	Switch-button 0/2/3 LED 2/4/6, LED driver ‡ 0/1/2 mm^2 Speaker 2/10/40 g, audio driver ‡ 1/2/5 mm^2	Switch-button 2/3/4 LED 3/5/8, LED driver ‡ 0/1/2 mm^2 1 LCD screen 5/25/100 cm^2, driver ‡ 0/1/2 mm^2.

° CMOS 0.25μm ‡ CMOS 0.13μm * CMOS 90nm ▲ CMOS 22nm △ CMOS 14 nm † Flash 45nm ◇ DRAM 57nm

Based on this methodology proposition, we modelled the 18 IoT device types inventoried for our study, as below (see Table 103).

As the large variety of equipment makes a detailed assessment impossible. The chosen approach allows for a more exhaustive accounting of impacts, at the cost of precision. Moreover, the IoT hardware profiles are subject to discussions.

Table 103 - IoT hardware specification profile

	Actuators	PCB	Power supply	Others	Security	Memory	Sensing	Processing	Casing	Connectivity	User interface
IoT - Security - Video	0	2	0	2	1	2	3	2	3	3	1
IoT - Security - Control	0	0	1	0	1	0	2	0	1	0	1
IoT - Automation - Water Heating	2	1	0	1	0	1	2	0	1	1	0
IoT - Automation - Street Lights	2	3	0	3	0	1	2	1	3	2	0
IoT - Automation - Space Conditioning	2	2	0	2	0	1	2	1	2	1	0
IoT - Automation - Lightning	2	1	0	1	0	1	2	1	0	1	0
IoT - Automation - Cooking	2	1	0	1	0	1	2	1	0	1	0
IoT - Automation - Audio	0	1	0	1	0	1	0	2	2	2	2
IoT - Automation - Appliances	2	1	0	1	0	1	2	1	1	1	0
IoT - Smart Meters	0	2	0	2	0	1	2	1	1	1	3
IoT - Sensors: Res - Wi-Fi	0	1	2	1	0	0	2	0	0	1	0
IoT - Sensors: Res - LE	0	1	2	1	0	0	2	0	0	1	0
IoT - Sensors: Industry - LE	0	1	2	1	0	0	2	0	0	1	0
IoT - Sensors: Health - LE	0	1	2	1	1	0	2	0	0	1	0
IoT - Gateway: Bus	0	3	0	3	0	2	0	3	1	3	0
IoT - Gateway: LE to Wi-Fi	0	3	0	3	0	2	0	3	1	3	0
IoT - Comm Building Control	0	3	0	3	0	1	0	3	3	2	0
IoT - Blinds + Windows	3	1	0	1	0	1	2	1	2	1	0

3.1.5.15. Summary table of Tier 1 — User equipment

3.1.5.15.1. Number of units

Table 104 - Number of devices – summary

Category of device	Data [expressed in units, otherwise specified]	Date	EU28 / EU27 / Europe regional market
Phones	836,129,202	2019	EU28
Smartphones	473,567,151	2019	EU28
Feature phones	41,179,752	2019	EU28
Phones (land line)	321,382,299	2019	EU28
Tablets	156,091,954	2019	EU28
Laptops	273,333,333	2019	EU28
Desktops	125,266,207	2019	EU28
Docking stations	6,696,300	2019	EU28
Projectors	7,084,138	2019	EU28
Electronic displays	312,528,573 Area: 150.43 km²	2019	EU28
Regular monitors	54,397,952 Area: 8.64 km²	2019	EU28
Special monitors	5,708,427 Area: 0.91 km²	2019	EU28
Regular signage display	26,894,490 Area: 21.35 km²	2019	EU28
Special signage display	13,432 Area: 0.04 km²	2019	EU28
TVs	225,514,272 Area: 119.49 km²	2019	EU28
TV box	208,328,200	2019	EU28
IPTV	29,925,600	2019	EU28
Satellite	65,606,100	2019	EU28
Cable	57,549,200	2019	EU28
Terrestrial	55,247,300	2019	EU28
Game consoles	170,842,765	2019	Regional market
Desktop consoles	90,010,347	2019	Regional market
Mobile game consoles	51,730,218	2019	Regional market
Printers	127,667,700	2019	EU28
External drives	626,286,100	2019	EU28
SSD	7,031,100	2019	EU28
HDD	32,515,000	2019	EU28
USB key	586,740,000	2016	EU28
Connected speakers	42,691,700	2019	EU28
IoT connected objects	1,499,013,789	2020	EU28
Number of equipment – excl. IoT	**2,892,946,172**		
Number of equipment – incl. IoT	**4,391,959,961**		

3.1.5.15.2. Energy consumption

Table 105 - Energy consumption – summary

Category of device	Data [expressed in kWh/year/ device, otherwise specified]
Phones	
Smartphones	3.9
Feature phones	0.09
Phones (land line)	17.57
Tablets	19.4
Laptops	30.96
Desktops	104.39
Docking stations	1.28
Projectors	200
Electronic displays	
Regular monitors	70
Special monitors	Range of value, see corresponding chapter
Regular signage display	
Special signage display	
Household TV	179
Hospitality TV (hostels, hospitals)	179
TV box	73
IPTV	73
Satellite	73
Cable	73
Terrestrial	73
Game consoles	
Desktop consoles	142.3
Mobile game consoles	8.6
Printers	Range of value, see corresponding chapter
External drives	
SSD	0.10
HDD	0.29
USB key	0.04
Connected speakers	23
IoT connected objects	Range of value, see corresponding chapter

3.1.5.15.3. Typical lifespan

Table 106 - Typical lifespan – summary

Category of device	Typical lifespan [expressed in years]
Phones	
Smartphones	2.5
Feature phones	2.5
Phones (land line)	8
Tablets	3
Laptops	4
Desktops	5.5
Docking stations	5
Projectors	5
Electronic displays	7
Regular monitors	6
Special monitors	6
Regular signage display	6
Special signage display	6
TVs	8
TV box	5
IPTV	5
Satellite	5
Cable	5
Terrestrial	5
Game consoles	6.5
Desktop consoles	6.5
Mobile game consoles	6.5
Printers	5
External drives	5
SSD	5
HDD	5
USB key	5
Connected speakers	5
IoT connected objects	4-12 years

3.1.6. Tier 2 – Network

3.1.6.1. General information

3.1.6.1.1. How the network is constituted and what are the different types of networks assessed in the scope of the study?

There is a large variety of networks. In this study, the following networks are considered:

Fixed-line networks
xDSL
FTTx (fiber)
Mobile networks
2G
3G
4G
5G

5G technology is included, as it the data sent by the operators doesn't allow a distinction between the different mobile generations. However, it is to be noted that 5G represents less than 1% of the technology mix of the 2019 mobile network in Europe.[111]

Other networks (e.g. TV/radio networks, PSTN (Public Switched Telephone Network) or enterprise networks) are not considered due to a lack of data. This has been addressed in chapter 5.1.1 Sensitivity analysis on excluded devices and networks.

Due to the use of many the same equipment for different technologies, the assessment will be separated in:

- Mobile network
- Fixed-line network

Scope includes the IT equipment, cables (copper and optical fibre) and energy consumption of:

- Access network (including modem)
- Aggregation network
- Core network & Backbone

3.1.6.1.2. Different technologies of fixed-line networks: xDSL and FTTx

In the EU-28 in 2019, the two main fixed-line networks were the xDSL and the FTTx.

xDSL: Digital Subscriber Line relies on telephone lines (copper) to provide internet access. It allows bit rates up to 100 Mbit/s.

FTTx: Fibre To The x, also called fibre, relies on optical fibres to provide internet access, up to either:

- FTTP: premise
- FTTH: home
- FTTB: building

It allows bit rates in the order of magnitude of 1 Gbit/s

In Europe, FTTx represents 20% of the technology mix coverage for fixed networks in 2019.[112]

3.1.6.1.3. Inventory of the xDSL and FTTx in the EU-28

The number of subscribers (thus internet routers) is based on the ICT impact study[113] for 2019:

- FTTx subscribers: 65,908,000
- xDSL subscribers: 205,641,000

3.1.6.1.4. Different generations of mobile networks: 2G, 3G, 4G, 5G

In the EU-28 in 2019, the three main mobile networks were the 2G, 3G and 4G networks. The 5G network was only beginning its deployment, representing less than 1% of the network in 2019.[114]

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111 GSMA, 2020. *The Mobile Economy 2020.* [online] Available at: <https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/03/GSMA_MobileEconomy2020_Global.pdf> [Accessed 30 September 2021].

112 European Comission. 2020. *Digital Economy and Society Index (DESI) 2020.* [online] European Commission. Available at: <https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67086> [Accessed 30 September 2021].

113 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.60. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

114 GSMA, 2020. *The Mobile Economy 2020*, p.10. [online] Available at: <https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/03/GSMA_MobileEconomy2020_Global.pdf> [Accessed 30 September 2021].

2G mobile network: also called Global System for Mobile Communications (GSM), 2G mobile network uses the 900 MHz and 1800 MHz radio frequencies in Europe. In Europe, 2G represented about 14% of the technology mix for mobile networks in 2019.[115]

3G mobile network: also called Universal Mobile Telecommunications System (UMTS), 3G mobile network uses various frequencies in Europe, among those, 420 MHz, 450 MHz, 900 MHz, 1800 MHz, 2100 MHz. In Europe, 3G represented about 28% of the technology mix for mobile networks in 2019.[116]

4G mobile network: also called Long Term Evolution (LTE-Advanced), 4G mobile network uses various frequency bands in the EU, among those, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2600 MHz. In Europe, 4G represented about 58% of the technology mix for mobile networks in 2019.[117]

5G mobile network: Sometimes called NR (New Radio), 5G mobile networks uses 3 different type of spectrum ranges in the EU: 700 MHz, 3.4 – 3.8 GHz, >24 GHz. In Europe, 5G represented less than 1% of the technology mix for mobile networks in 2019, as its deployment was just beginning.[118]

3.1.6.2. Modelling approach

3.1.6.2.1. Manufacturing, distribution and end of life

On the contrary to tiers 1 and 3 approach, the network equipment impacts could not be based on the number of devices installed and their lifespan. Indeed, it is difficult to determine lifespan of network related devices.

For this reason, the chosen approach is to consider all devices installed on a given year (2020), and consider that their manufacturing, distribution and end of life phases related impacts occurs at that moment. It leads to some uncertainty as the volume of installed devices may vary from one year to another.

There is an exception for copper cable and optical fibre. For those the length of installed cable was not known, but the total length of installed cables was known. We used the following hypotheses:

- Final connection to the client: 10 years lifespan
- Other cables: 20 years lifespan

This study is based on data from a French study listing devices installed in 2020, which has been extrapolated to EU-28.

Although an estimate of the environmental impacts of the European network on the basis of an extrapolation from the French network to the European network represents a certain degree of uncertainty, this uncertainty remains low for several reasons:

- France represents 13% of the European population alone and 14.2% of the territory of the EU (source DESI 2019 dataset), which are two parameters of great importance for measuring the rate of network equipment in a given territory.
- France has a territory with a varied geography (areas of urban and rural plains, mountainous areas, coastal areas), fairly representative of the geographical variations that there may be within the EU-28. The variation in the topography and the urban density of a territory is a major factor in the variability of the density of mobile network equipment (base stations, routers).
- The European network is developed relatively homogeneously, with (data from DESI 2019 dataset):
  - a minimum fixed network coverage of 83.5% (Poland), maximum of 100% (several countries) and average of 97.1%, compared to the fixed network in France (coverage of 100%),
  - and a minimum European 4G mobile network coverage of 80.7% (Bulgaria), maximum of 100% (several countries), and an average of 96.5%, compared to the mobile network in France (coverage of 98.6%).

115 *Ibid.*
116 GSMA, 2020. *The Mobile Economy 2020*, p.10. [online] Available at: <https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/03/GSMA_MobileEconomy2020_Global.pdf> [Accessed 30 September 2021].
117 *Ibid.*
118 *Ibid.*

The extrapolation has been performed as follow:

- Fixed-line networks related devices: the extrapolation is based on the ratio of data transmitted in Europe with fixed-line networks over one year (518 EB (Exabyte)) related to the data transmitted in France with fixed-line networks over one year (83.3 EB), so a multiplication of 6.21.
- Mobile networks related devices: the extrapolation is based on the ratio of data transmitted in Europe with mobile networks over one year (64 EB (Exabyte)) related to the data transmitted in France with mobile networks over one year (6.94 EB), so a multiplication of 9.23.
- Shared devices: those are used by both mobile and fixed-line network, in the aggregation and core network. An allocation based on the amount of data used by both networks type was used, considering:
- 64 EB of data for mobile networks per year, meaning 11.0% of transmitted data
- 518 EB of data for fixed-line networks per year, meaning 89.0% of transmitted data
- Then each allocated part has been addressed based on the two previous points.

If instead of using traffic, the extrapolation from France was done on the basis of coverage and therefore area, the EU being 7× larger than France for a similar population density, we would get a scaling factor of 7×. A similar factor would be obtained based on the number of users (since similar density). In this study, the scaling factor used is 6.21× for the fixed network and 9.23× for the mobile network, which brings quite close results in the end. See 5.3.2—Sensitivity analysis extrapolation to EU-28 in the study report for more information.

To summarize, the table below presents some examples (see Table 107 below).

Each piece of equipment has been assessed with the EIME software and database, based on Bureau Veritas and APL expertise.

Infrastructure has not been included due to a lack of data. Indeed, the network can be installed on existing or dedicated sites, with an unknown lifespan. Some analyses have been performed based on French broad scale data on structural work. It showed that infrastructure account for a few percent with the selected hypotheses, which is in line with the datacentre infrastructure. Nonetheless, the exclusion of infrastructure is inconsistent with the data centre assessment and should be updated with more precise data.

Table 107 - Example of network device quantities extrapolation

Device	Type of network	Extrapolation formula
DSLAM	Fixed-line	Ratio of data transmitted in Europe with fixed-line networks over one year (518 EB (Exabyte) related to the data transmitted in France with fixed-line networks over one year (83.3 EB), so a multiplication of 6.21
Collection router	Mobile	Ratio of data transmitted in Europe with mobile networks over one year (64 EB (Exabyte) related to the data transmitted in France with mobile networks over one year (6.94 EB), so a multiplication of 9.23
Aggregation WDM	Shared	518 EB of data for fixed-line networks per year, meaning 89.0% of transmitted data Ratio of data transmitted in Europe with fixed-line networks over one year (518 EB (Exabyte) related to the data transmitted in France with fixed-line networks over one year (83.3 EB), so a multiplication of 6.21
		64 EB of data for mobile networks per year, meaning 11.0% of transmitted data Ratio of data transmitted in Europe with mobile networks over one year (64 EB (Exabyte) related to the data transmitted in France with mobile networks over one year (6.94 EB), so a multiplication of 9.23

3.1.6.2.2. Use

Data from the ICT impact study[119] have been used to determine the electricity consumption of fixed-line and mobile networks, as follow:

- Fixed-line networks energy consumption: 17.7 TWh. This value does not include the energy consumption related to modems; it has been added based on the number of devices and the associated consumption.
- Mobile networks energy consumption: 15.17 TWh.

In the IEA report from 2017, Digitalization & Energy[120], data networks consumption is described as being “around 185 TWh globally in 2015, or around 1% of global electricity use. Mobile networks accounted for around two-thirds of the total.” On the basis of this report and of other litterature sources (Malmodin & Lundén, 2016, 2018, Pihkola, 2018), we can estimate that the electrical consumption of the RAN to 0.5% to 0.7% of the total electrical consumption. Therefore, applied to EU-28, the consumption of the RAN would be between 15 to 21 TWh, which is close to the estimate used above.

In his contribution to the Electronic Goes Green 2020 report published by Fraunhofer IZM[121], Malmodin estimates that the average electricity use for EU-28 countries in 2020 is 25kWh/subscriber/year. Based on the number of inhabitants in the EU-28 in 2019, this would result in an estimated consumption of 12.84 TWh, which is also close to the estimate used above.

3.1.6.3. Fixed-line network

3.1.6.3.1. Modelling of the manufacturing, distribution and end of life phases

The number of installed devices in Europe is based on information from a survey of the main French operators for France[122], extrapolated to Europe.

Table 108 - Fixed-line network devices

ACCESS	
Network	**Equipment**
Shared	OAN (Optical Access Node) and/or MDF (Main Distribution Frame) site collection router/switch
	Optical fibre
	Copper cable
xDSL	IAD (Integrated Access Device) / CPE (Customer Premise Equipment) router
	DSLAM (Digital Subscriber Line Access Multiplexer)
FTTH fibre	IAD/CPE router without ONT (Optical Network Termination) / SFP (Small Form-factor-Pluggable)
	ONT (external)
	IAD router with ONT/SFP
	OLT (Optical Line Termination)
FTTLA fibre	IAD/CPE cable router

AGGREGATION	
Network	**Equipment**
Shared	Aggregation router*
	Aggregation WDM* (Wavelength Division Multiplexing)

BACKBONE	
Network	**Equipment**
Shared	Backbone WDM* (Wavelength Division Multiplexing)
	P-PE-Peering router
	Fixed DNS

119 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.73. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

120 IEA, 2017. *Digitalization & Energy*. [online] Available at: <https://iea.blob.core.windows.net/assets/b1e6600c-4e40-4d9c-809d-1d1724c763d5/DigitalizationandEnergy3.pdf> [Accessed 1 October 2021].

121 Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration, 2020. *Electronics Goes Green 2020 Proceedings*. [online] Available at: <https://online.electronicsgoesgreen.org/wp-content/uploads/2020/10/Proceedings_EGG2020_v2.pdf> [Accessed 1 October 2021].

122 The survey has been performed in 2021, based on 2020 data related to Orange, SFR, Bouygues and Free data and gathered by the ADEME. Those operators represent the vast majority of network connections in France (91% of mobile subscribers)

AGGREGATION AND BACKBONE OPTICAL FIBRES	
Network	**Equipment**
Shared	Optical fibre – 12 strands
	Optical fibre – 24 strands
	Optical fibre – 48 strands
	Optical fibre – 72 strands
	Optical fibre – 96 strands
	Optical fibre – 144 strands
	Optical fibre – 288 strands
	Optical fibre – 576 strands
	Optical fibre – 720 strands

* Note: those devices are shared between mobile and fixed-line networks. An allocation based on the total data transfer has been performed.

3.1.6.3.2. Modelling of the use phase

Data from the ICT impact study[123] indicates that the fixed-line networks energy consumption: 17.7 TWh.

This value does not include the energy consumption related to modems. In order to determine this value, the study is based on the number of subscribers (thus internet routers) and their respective electricity consumption.

The number of subscribers is based on the Eurostat, 2020; DESI, 2020; Authors' calculation[124] for 2019:

- FTTx internet routers: 80,812,332
- xDSL internet routers: 115,157,573

The electricity consumption is based on manufacturer data, and is as follow:

- FTTx routers: 11.25 W in active mode 4.5 hours per day and 8.86 W in standby mode 19.5 hours per day for a total of 82 kWh per year.
- xDSL routers: 14.4 W in active mode 4.5 hours per day and 10.5 W in standby mode 19.5 hours per day for a total of 98 kWh per year.

The total electricity consumption is then:

Table 109 - Fixed-line network – routers electricity consumption

Network	Number of internet routers	Electricity consumption per year per router [kWh]	Total electricity consumption per year [TWh]
FTTx	80,812,332	82	6.59
xDSL	115,157,573	98	11.33

123 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.73. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

124 The number of households subscriptions to an internet access has been calculated based on the following sources: (1) 90% households equiped, source: https://ec.europa.eu/eurostat/product?code=isoc_ci_in_h&mode=view&language=EN (2) Number of households in EU28: 224 478 700 https://ec.europa.eu/eurostat/databrowser/view/lfst_hhnhtych/default/table?lang=en
The number of subscribers has been calculated based on the number of internet subscribers in the EU28 calculated above, and the proportion of Fibre, Cable, and xDSL subscribers in the internet subscribers in the EU28 based on the DESI 2020 report (2019 data).

3.1.6.4. Mobile Network

3.1.6.3.1. Modelling of the manufacturing, distribution and end of life phases

The number of installed devices in Europe is based on information from a survey of the main French operators for France, extrapolated to Europe.

Table 110 - Mobile network devices

ACCESS	
Network	**Equipment**
Shared	Passive multiband antenna (1.4m à 2.7m)
	RU (700, 800, 900, 1800, 2100, 2600MHz) amplifier
	RRU (Remote Radio Unit) /RRH (Remote Radio Head) (700, 800, 900, 1800, 2100, 2600MHz) amplifier
2G (GSM)	BTS (Base Transceiver Station) - BBU (BaseBand Unit) 2G
3G (UMTS)	NODEB - BBU 3G
4G (LTE)	ENODEB - BBU 4G
5G (NR)	GNODEB - BBU 5G
	AAS - Antenne Active 3,5GHz
Transport	Collection router
	ODU (OutDoor Unit) - Passive antenna
	ODU - RF (Radio Frequency) amplifier
	IDU (InDoor Unit)

AGGREGATION AND BACKBONE OPTICAL FIBRES	
Network	**Equipment**
Shared	Optical fibre – 12 strands
	Optical fibre – 24 strands
	Optical fibre – 48 strands
	Optical fibre – 72 strands
	Optical fibre – 96 strands
	Optical fibre – 144 strands
	Optical fibre – 288 strands
	Optical fibre – 576 strands
	Optical fibre – 720 strands

AGGREGATION	
Network	**Equipment**
Shared	Aggregation router*
	Aggregation WDM (Wavelength Division Multiplexing) *
	Security Gateway 4G/5G

BACKBONE	
Network	**Equipment**
Shared	Backbone WDM (Wavelength Division Multiplexing)*
	P-PE-Peering router
	MME (Mobility Management Entity) /SGSN (Serving GPRS support node)
	HSS (Home Subscriber Server) /HLR (Home Location Register)
	SP-GW (Serving/PDN-Gateway) /GGSN (Gateway GPRS Support Node)
	PCRF (Policy and Charging Rules Function)
	Gi (Gateway-Internet) LAN (Local Area Network)
	DNS (Domain Name System) Mobile / Roaming
	FW (FireWall) Roaming

* Note: those devices are shared between mobile and fixed-line networks. An allocation based on the total data transfer has been performed.

3.1.6.4.2. Modelling of the use phase

Data from the ICT impact study[125] indicates that the mobile networks energy consumption is 10.5 TWh for the EU-27 in 2020. The data was interpolated between 2015-2020 to obtain 2019, and extrapolated to the UK to obtain EU-28 consistency, based on the extrapolation factor proposed by the ICT impact study, resulting in a 15.2 TWh energy consumption in 2019 for the EU-28.

3.1.7. Tier 3 – Data centres

3.1.7.1. General information

3.1.7.1.1. How data centres are constituted and what are the different types assessed in the scope of the study?

Data centres are defined by EN 50600-1[126] as "structures or group of structures, dedicated to the centralised accommodation, interconnection and operation of information technology and network telecommunication equipment providing data storage, processing and transport services together with the facilities and infrastructures for power distribution and environmental control, together with necessary levels of resilience and security required to provide the desired service availability."

This definition covers a large scope of data centres which could refer to a 10m2 server room integrated in an office building to hyperscale data centres, standalone building, composed of tens of thousands of IT room.

Data centres are composed of different of spaces and equipment's associated to different level of services and usage:

- 1. Level "**Building and technical infrastructure**": which includes all the architectural components (concrete, structure, carpentry, sealing, surface treatment…) and all the technical equipment's dedicated to the data centre's facilities.

The mains Data centres facilities are:

- Air conditioning: production, distribution and emission of chilled air, air treatment to maintain the IT equipment in an environment compatible with its requirements
- High quality electricity provisioning and distribution: from high voltage provided by grid to high quality low voltage in the IT room
- Electrical backup: to guarantee an uninterrupted power supply in case of failure from the grid
- Security: video surveillance and control of the access to maintain physical security
- Safety: fire detection and protection
- Connectivity: point of connexion to network operators

This level provided spaces in data centres compliant with the hosting of the Information Technology equipment's requirements.

- 2. Level "**Information Technology**" which includes the IT equipment's hosted within the IT and network room (also called white spaces) of the data centre.

The IT equipment's can be classified in 3 categories aligned with the 3 mains generic functions of the data centre:

- Computing: data processing provided by server type equipment
- Storage: data storage, provided by drives (HDD, SDD) implemented in dedicated storage rack or in servers
- Networking: connection to external network and between the equipment within the data centre provided by switches, routers and passives equipment.

……………

125 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.73. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

126 CENELEC, 2019. EN 50600-1:2019 - *Information technology - Data centre facilities and infrastructures - Part 1: General concepts. CLC/TC 215 - Electrotechnical aspects of telecommunication equipment.* [online] Available at: <https://standards.iteh.ai/catalog/standards/clc/a5141043-2dcd-4dbf-acc6-576a94a2cddc/en-50600-1-2019> [Accessed 1 October 2021].

The figure below (Figure 23) presents a representation of a standalone data centre and its different spaces, equipment and functions.

3.1.7.1.2. What are the parameters considered related to the data centre?

Data centres are generally characterized by the following parameters:

- **Type and usage:** related to ownership of the IT equipment and infrastructure and the services provided
- **Architecture:** integrated into a larger building or standalone dedicated building
- **Availability:** the level of availability chosen in the design phase determines the redundancy of the infrastructure equipment installed.
- **Surface area:** a data centre can have a surface area of computer rooms ranging from a few dozen square meters included in a building to several tens of thousands of square meters.
- **Density:** the density expressed in kW or kVA per bay or square meter defines the maximum power that could be used by the computer equipment within a bay or a square meter.
- **Location:** Geographic location and climatic conditions influence the energy performance of the data centre.

In relation with these parameters, several classifications of data centre are detailed in the literature.

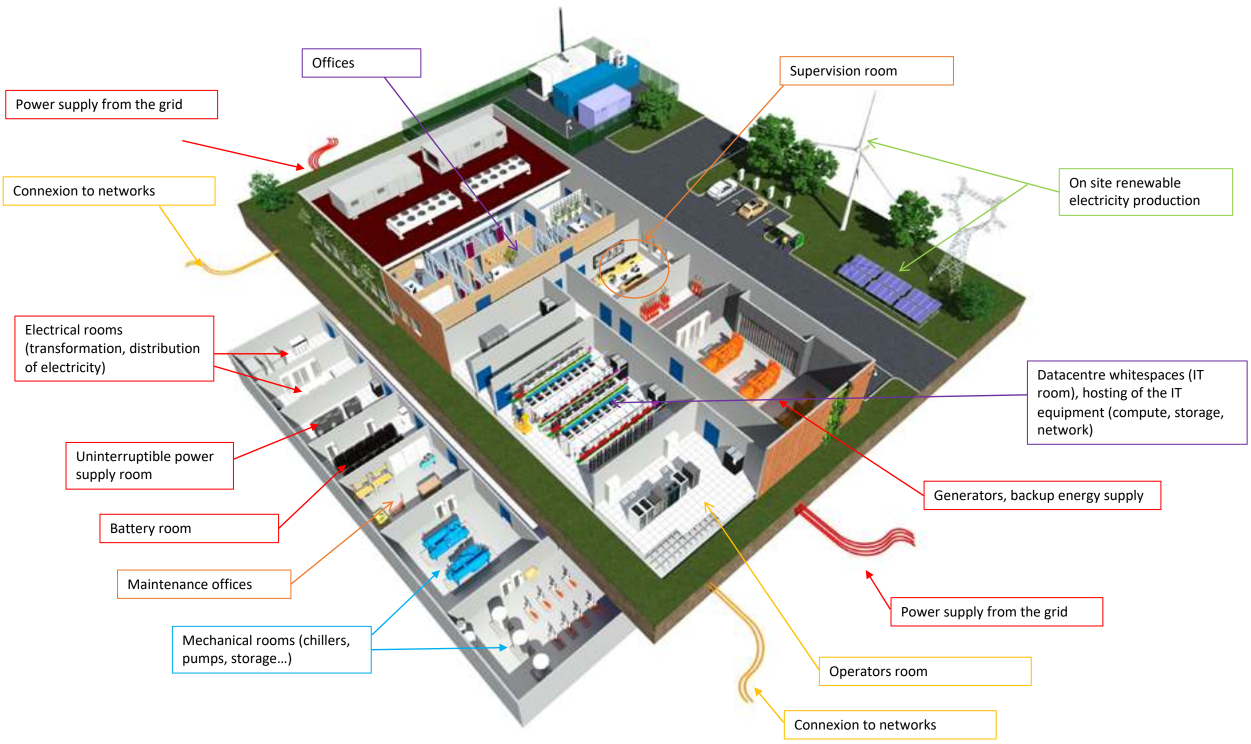
3.1.7.2. Overview of existing studies for the European scope

Several studies have handled with the issue of characterisation of data centres in Europe and assessment of associated the energy consumption.

The most recent studies detailed at the European level are:

- Masanet, E., Shehabi, A., Lei, N., Smith, S., and J.G. Koomey (2020). "*Recalibrating global data centre energy use estimates.*" Science, Vol 367, Iss 6481. with an open-source calculation files[127] used in the ICT Impact Study [128].

Figure 9 - Representation of a standalone data center and its different spaces (technical and IT spaces)



127 Masanet, E., Shehabi, A., Lei, N., Smith, S., and J.G. Koomey (2020) "Recalibrating global data center energy use estimates." Science, vol 367, ISS 6481.

128 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, p.29. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

- Hintemann, R., Hinterholzer, S., Montevecchi, F., & Stickler, T. (2020). *Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market*. Borderstep Institute & Environment Agency Austria named after as "Borderstep Institute Model".[129]
- Dodd, N., Alfieri, F., Maya-Drysdale, L., Viegand, J., Flucker, S., Tozer, R., Whitehead, B., Wu, A., Brocklehurst F., *Development of the EU Green Public Procurement (GPP) Criteria for Data Centres Server Rooms and Cloud Services*, Final Technical Report, EUR 30251 EN, Publications Office of the European Union, Luxembourg, 2020, named after as "JRC assessment"

Three different calculation models are used in these studies. This chapter details the different hypothesis and perimeter to identify the most relevant data to use in the assessment of the environmental impacts of ICT in Europe.

3.1.7.2.1. Development of the EU Green Public Procurement (GPP) Criteria for Data Centres Server Rooms and Cloud Services

Perimeter: EU 28, exclusion criteria for:

- small datacentres of an IT capacity equal or lower than 25 kW
- datacentres that do not have provisioning for power and environmental management separate from other aera or do not have a dedicated building

Methodology: Approach based on data provided by Data centre Dynamic Sensus (2013) and other research samples were used to estimate the numbers, space, power and /or rack profile within European markets (EU-28), regionally and globally. Data completed by self-reported information and crossed with published sources. The representation of the enterprise market was calculated as a statistical function. Number of data centre was estimated from data collected on data centre white spaces.

Breakdown between IT and non-IT energy consumption based on US Data centre Energy Usage Report (June 2016).

Breakdown between type of data centre done by collecting data on the annual energy consumption of data centres in the EU by the European Commission.

Classification of data centre:

- **Enterprise data centre:** a data centre which has the sole purpose of the delivery and management of services to its employees and customers and that is operated by an enterprise
- **Co-location data centre:** a data centre facility in which multiple customers locate their own network, servers, and storage equipment

Table 111 - Main data provided by the JRC assessment

Topic	Data	Value
Data centre overview	Total white spaces	Entreprise data centers: 3,629,250 m² Co-Location data centres: 2,562,000 m² MSP data centres: 170,660 m² **TOTAL: 6,361,910 m²**
	Average white space	Entreprise data centers: 60 m² Co-Location data centres: 1,152 m² MSP data centres: 1,123 m²
	Number of data centres	Entreprise data centers: 60,215 Co-Location data centres: 2,215 MSP data centres: 152 **TOTAL: 62,582**
Energy	Total DC energy consumption	**Total EU DC Energy consumption: 104 TWh in 2020** **(98 TWh in 2019 interpolated from 2015-2020 consumption)** Average PUE = 1.54
IT Equipment	Amount of equipment	Servers: no information Storage: no information Network: no information
Non IT Equipment	Amount of equipment	UPS : no information Battery: no information Chillers: no information Generators: no information
Others	Other information	No information

129 Hintemann, R., Hinterholzer, S., Montevecchi, F., & Stickler, T. (2020). *Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Borderstep Institute & Environment Agency Austria.* Available at: <https://digital-strategy.ec.europa.eu/en/library/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market> [Accessed 30 September 2021].

- **Managed Service Providers data centre (MSP):** a data centre offering server and data storage services where the customer pays for a service and the vendor provides manages the required ICT hardware/software and data centre equipment.

Conclusion

The geographical scope of this study is in line with the present assessment and cover a large definition of data centre. However, the data on which the study is based appears to be too old to be considered for a 2019 assessment. Thus, the JRC report states "some data centre experts believe this data are overestimated", and this study do not provide details on the ICT equipment hosted within the data centre.

3.1.7.2.2. Recalibrating global data centre energy use estimates

Perimeter: Worldwide study detailed by region (Asia Pacific, Central and Eastern Europe, Latin America, Middle East and Africa, North America, Western Europe). Extrapolation to EU 27 by a 1.06 factor proposed by the ICT impact study based on Western Europe data.[130] Exclusion criteria for:

Computing equipment

Methodology: Approach based on data provided by CISCO on ICT equipment's stock at a global and regional level (2018).[131] Energy consumption is estimated using average power by ICT equipment and average PUE by type of data centre. Some data are detailed at the Western Union scope, extrapolation to EU-27 is done by a 1.06 multiplication and a 1.2 multiplication to obtain EU-28 (ICT impact study).[132]

Table 112 - Main data provided by the ICT impact study, 2020 & Masanet, 2020 (2019 data)

Topic	Data	Value
Data centre overview	Total white spaces	No information
	Average white space	No information
	Number of data centres	No information
Energy	Total DC energy consumption	**Western Europe basis extrapolated** **Total DC Energy consumption:** **37.9 TWh for Western Europe** **40.2 TWh for EU27** **45.5 TWh for EU28** PUE traditional data centre: 1.99 PUE Cloud data centre: 1.58 PUE Hyperscale data centre: 1.17
IT Equipment	Amount of equipment	**Servers: Regional Western Europe** Traditional data centres: 2,531,000 Cloud data centres: 2,536,000 Hyperscale data centres: 3,801,000 **Storage: Global** Traditional data centre: 17 million drive SSD and 20 million drive HDD Cloud data centre: 35 million drive SSD and 42 million drive HDD Hyperscale data centre: 51 million drive SSD and 61 million drive HDD **Network: Global** Traditional data centres: 56 million ports installed Cloud data centres: 65 million ports installed Hyperscale data centres: 95 million ports installed
Non-IT Equipment	Amount of equipment	UPS: no information Battery: no information Chillers: no information Generators: no information
Others	Other information	Details of the energy consumptions by ICT equipment at the Western Europe scope

130 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, pp.3, 29. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

131 Cisco, 2018. *Cisco Global Cloud Index: Forecast and Methodology, 2016-2021. White Paper*. [online] Available at: <https://virtualization.network/Resources/Whitepapers/0b75cf2e-0c53-4891-918e-b542a5d364c5_white-paper-c11-738085.pdf> [Accessed 1 October 2021].

132 VHK and Viegand Maagøe for the European Commission. 2020. *ICT Impact Study, Assistance to the European Commission - ICT Impact study - FINAL REPORT.* [online] European Commission - Energy, pp.3, 29. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

Classification of datacentre:

- Traditional data centre
- Cloud data centre
- Hyperscale data centre

Conclusion

The geographical scope of the primary study used in the model is a worldwide scope, with a regional segmentation for Western Europe and Central and Eastern Europe, that appears only on the energy mix and the server stock. The ICT impact study assumed that Western Europe data from Cisco, used to estimate the number of servers per category, "is basically the EU-15"[133], and have done an extrapolation base on GDP, inhabitants, residential and business services to estimate EU-27. There is therefore a high level of uncertainty to the figures, related to the inherent limits of an extrapolation and the limited data on IT equipment described at the European scale.

3.1.7.2.3. Borderstep Institute Model

Perimeter: European Union 28, where countries were divided into the following regions:

- Eastern Europe: Bulgaria, Czechia, Hungary, Poland, Romania, Slovakia
- Northern Europe: Denmark, Estonia, Finland, Ireland, Latvia, Lithuania, Sweden, United Kingdom of Great Britain, and Northern Ireland
- Southern Europe: Croatia, Greece, Italy, Malta, Portugal, Slovenia, Spain
- Western Europe: Austria, Belgium, Luxembourg, France, Germany, Netherlands

Methodology: Approach based on data provided by IDC on ICT equipment's stock (2018) and adapted at the EU 28 level. Data are provided for 2018 (and 2020 forecast).

Table 113 - Main data provided by Borderstep Instiitute, 2020 (2018 and 2020 data)

Topic	Data	Value
Data centre overview	Total white spaces	No information
	Average white space	No information
	Number of data centres	No information
Energy	Total DC energy consumption	**Total DC Energy consumption: 76.8 TWh (2018) and 79.98 TWh (2019)** Average PUE = 1.75 (2018), 1.71 (2020)
IT Equipment	Amount of equipment	**Servers: in thousands of devices** High-end servers: 18 (2018), 17 (2020) Mid-range servers: 453 (2018), 418 (2020) Volume servers: 10,613 (2018), 10,722 (2020) Application specific hardware: 135 (2018), 159 (2020) **Storage: in thousands of devices** 3.5"Hard disk: 39,703 (2018), 39,639 (2020) 2.5"hard disk: 47,439 (2018), 50,210 (2020) SSD: 34,638 (2018), 50,224 (2020) Storage controller: 982 (2018), 925 (2020) **Network: in thousands of ports** 1 Gbit: 7,515 (2018), 2,974 (2020) 10 Gbit: 26,344 (2018), 22,830 (2020) 40/100 Gbit: 6,905 (2018), 13,583 (2020) Storage ports: 27,499 (2018), 27,749 (2020)
Non-IT Equipment	Amount of equipment	UPS: no information Battery: no information Chillers: no information Generators: no information
Others	Other information	Breakdown of the energy consumptions by ICT equipment and non-ICT equipment at the EU 28 scope. Breakdown of the energy consumptions per type of data centre at the EU28 scope. Breakdown of the energy consumptions by EU regions

133 *Ibid*, p.3.

The Borderstep assessment is a multi-layered calculation model contains three basics parameters:

- Type and number of devices (product group)
- Load profiles (usage parameters)
- Load-dependant electrical power consumption (technical parameters)

Classification of datacentre:

- Cloud data centre
- Traditional data centre
- Edge data centre

Conclusion

The Borderstep Institute Model is in line with the geographical perimeter of the present study (EU-28) and is based on data from 2018 with detailed information on IT equipment in 2018 and 2020.

3.1.7.2.4. Modelling approach

Considering time and geographical consistency, this study is based on data from the calculation model developed by Borderstep (Hintemann et al., 2020).[134]

Some additional missing data related to the superficies and architectures of the data centre have been calculated bases on APL DATA CENTER's expertise and experience.[135] Additional data have been provided by Borderstep to adapt their model to the year 2019.

The principal energy used in data centre is electricity mainly provided by the grid and by generators in case of failure of the main source of energy.

Within the data centre electrical consumption are split between IT (server, network and storage) and non-IT equipment (chillers, CRAC units, UPS...).

The energy performance is generally assessed through the Power Usage Effectiveness (PUE) indicator.

PUE is standardised by ISO 30134-2:2016 and defined as the ratio of the total amount of energy used by the data centre facility to the energy delivered to the IT equipment, based on annual consumptions data.

3.1.7.2.5. ICT equipment

Definition

IT equipment can be defined in three main categories:

Servers: The Regulation 2019/424/EU on servers and data storage[136] defines the product group as follows:

> (1) 'server' means a computing product that provides services and manages networked resources for client devices, such as desktop computers, notebook computers, desktop thin clients, internet protocol telephones, smartphones, tablets, tele-communication, automated systems or other servers, primarily accessed via network connections, and not through direct user input devices, such as a keyboard or a mouse and with the following characteristics:
>
> (a) it is designed to support server operating systems (OS) and/or hypervisors and targeted to run user-installed enterprise applications.
>
> (b) it supports error-correcting code and/or buffered memory (including both buffered dual in-line memory modules and buffered on board configurations).
>
> (c) all processors have access to shared system memory and are independently visible to a single OS or hypervisor.

Network[137]:

- Switch: "Switches are intelligent, high-performance hubs. As data is sent back and forth through the switch, it records MAC addresses (unique identification number for network-enabled hardware) for each sender and recipient. In this process, the switch learns which device is connected to which port. When a switch receives data on one port, it uses its address records to identify where traffic came from and to which device it should be forwarded. This ensures that information is only delivered to relevant computers rather than every device on the network"

134 Hintemann, R., Hinterholzer, S., Montevecchi, F., & Stickler, T. (2020). *Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Borderstep Institute & Environment Agency Austria.* Available at: <https://digital-strategy.ec.europa.eu/en/library/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market> [Accessed 30 September 2021].

135 UPS, Battery, Chiller, Generators

136 Commission Regulation European Union, 2019. *Commission Regulation (EU) 2019/424 of 15 March 2019 laying down ecodesign requirements for servers and data storage products pursuant to Directive 2009/125/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 617/2013.* [online] Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019R0424> [Accessed 1 October 2021].

137 Definition from RMON Networks. 2018. What's the Difference between a Switch, a Router, and a Firewall?. [online] Available at: <https://rmonnetworks.com/whats-the-difference-between-a-switch-a-router-and-a-firewall/> [Accessed 1 October 2021].

- Router: "While switches and hubs transmit data within a single network, routers are used to route data between different networks. These devices are positioned at gateways where two networks connect. For example a router could connect your home's LAN to your ISP's (internet service provider) network."
- Firewall: "Unlike routers and switches, firewalls are network security appliances. While routers (without firewall capabilities) blindly pass traffic between two separate networks, firewalls monitor the traffic and helps block unauthorized traffic coming from the outside trying to get into your network."

Storage: The Regulation 2019/424/EU on servers and data storage products defines the product group as follows:

- (10) 'data storage product' means a fully-functional storage system that supplies data storage services to clients and devices attached directly or through a network. Components and subsystems that are an integral part of the data storage product architecture (e.g., to provide internal communications between controllers and disks) are considered to be part of the data storage product. In contrast, components that are normally associated with a storage environment at the data centre level (e.g. devices required for operation of an external storage area network) are not considered to be part of the data storage product. A data storage product may be composed of integrated storage controllers, data storage devices, embedded network elements, software, and other devices.

Stock

The 2019 stock considered are the average value between 2018 and 2020 provided by Hintemann et al., 2020 (Borderstep Institute).[138]

Energy consumption

The 2019 energy consumptions of the ICT equipment hosted in data centre and the breakdown have been extracted from the EU-Cloud Study[139] (2019 is forecast).

Table 114 – ICT Equipment – Stock

ICT Equipment	Stock (units)		
	2018	2020	2019 (average value)
Servers			
High-end servers	18,000	17,000	17,500
Mid-range servers	453,000	418,000	435,500
Volume servers	10,613,000	10,722,000	10,667,500
Application specific hardware	135,000	159,000	147,000
TOTAL	**11,219,000**	**11,316,000**	**11,267,500**
Storage			
3.5 Hard disk	39,703,000	39,639,000	39,671,000
2.5 Hard disk	47,438,000	59,219,000	53,328,500
SSD	34,638,000	50,224,000	42,431,000
Storage controller	982,000	925,000	953,500
Networks ports			
1Gbit	7,515,000	2,974,000	5,244,500
10 Gbit	26,344,000	22,830,000	24,587,000
40/100 Gbit	6,905,000	13,583,000	10,244,000
Storage Ports	27,499,000	27,749,000	27,624,000
TOTAL	**68,263,000**	**67,136,000**	**67,699,500**

138 Hintemann, R., Hinterholzer, S., Montevecchi, F., & Stickler, T. (2020). *Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Borderstep Institute & Environment Agency Austria.* Available at: <https://digital-strategy.ec.europa.eu/en/library/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market> [Accessed 30 September 2021].

139 *Ibid.*

Table 115 - ICT equipment – Energy consumption

ICT equipment group	Annual energy consumption TWh (2019)
Servers	33.5
Storage	9.5
Networks	3.1
TOTAL	**46.1**

3.1.7.2.6. Non-IT equipment

Definition

The non-IT equipment dedicated to utilities in the data centres have been considered with two different approaches depending on the type of equipment.

- Main equipment has been assess based on the characteristic of the data centre at the European level: specific electrical load has been attributed to each category of data centre to define the installed power in MW. As conservative hypothesis, a TIER III level redundancy have been considered (n+1).
- Other equipment has been assess based on the data centre modelized by APL extrapolated at the European level based on Electrical power installed dedicated to the IT room.

The following hypothesis have been considered, based on the experiences of APL DATA CENTERS:

- Electricity provided by backup generators represent 0,5% of the electrical annual consumption (4h monthly test of the generators)
- 10 kg of refrigerant leakage by MW power of chillers installed
- Reference UPS model: 200kW average power with 10 mins autonomy on batteries
- Main equipment includes generators, chillers, uninterruptible power supply and batteries.
- Other equipment includes: CRAC, air handling units and tower, electrical cabinets, air ventilation duct, power transformer, cables, lighting, oil tank, fire detection & extinction system, supervision and monitoring equipment, electrical and network cabling, local renewable energy production, security equipment.

Stock

Breakdown of 2019 energy consumptions have been detailed by type of data centre is extracted from the EU-Cloud Study[140] (2019 is forecast).

Energy consumption

The 2019 energy consumptions of the ICT equipment hosted in data centre and the breakdown have been extracted from the EU-Cloud Study[141] (2019 is forecast).

Table 117 – Non-ICT equipment – Energy consumption

Non-ICT equipment group	Annual energy consumption [TWh]
TOTAL	**33.9**

3.1.7.2.7. Modelling

The building part of the data centre have been modelized considering the following hypothesis

- an average density of 5kWIT per rack and 2,5m2 per rack.
- based on a standard data centre design and build by APL data center with the following characteristics:
  - 25 years lifespan: In 25 years, the building will still be in place but certainly not adapted

Table 116 - Non-ICT equipment – Stock

<table>
<tr><th>Data centre</th><th>Annual Energy consumption, TWh (2019)</th><th>% electrical load</th><th>Estimated Power Installed MW (2019)</th><th>Estimated MW of Generators installed</th><th>Estimated IT Power Installed MW (2019)</th><th>Estimated MW of chillers installed (2019)</th><th>Estimated UPS (standard)</th><th>Estimated batteries</th></tr>
<tr><td>Cloud data centre</td><td>29.8</td><td>70%</td><td>4,860</td><td>6,804</td><td rowspan="4">9,234</td><td rowspan="4">11,081</td><td rowspan="4">55,406</td><td rowspan="4">3,601,376</td></tr>
<tr><td>Traditional data centre</td><td>47.9</td><td>50%</td><td>10,936</td><td>19,685</td></tr>
<tr><td>Edge data centre</td><td>2.2</td><td>35%</td><td>718</td><td>1,005</td></tr>
<tr><td>TOTAL</td><td>79.9</td><td>–</td><td>16,513</td><td>27,493</td></tr>
</table>

140 Hintemann, R., Hinterholzer, S., Montevecchi, F., & Stickler, T. (2020). *Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Borderstep Institute & Environment Agency Austria*. Available at: <https://digital-strategy.ec.europa.eu/en/library/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market> [Accessed 30 September 2021].

141 *Ibid.*

to the future IT equipment and Information System.

• TIER III level of resilience accredited by Uptime Institute Design and Constructed Facility stages

• 600m² of IT room

All the following components have specific lifespan and have been reported to 1 m2 of IT room to be extrapolated at a global scope.

- Roads and structures of concrete
  - Roads (heavy and light + pedestrian access): insulation layer, shape, foundation and finish
  - Ballasted columns diameter 400 mm
  - Column distribution mattress
  - Concrete for retaining walls, radiers and exteriors, infrastructure and superstructures
  - Walls of soubassemets, premurs
  - Concrete slabs
  - Borders, thresholds, statements
  - Concrete staircase
  - Bituminous coating
  - Buried isolation
  - Electricity network
  - Sheath and nozzles
  - sanitation
  - Buried pipes (EU/EP)
  - HVAC evacuation network and DIEI EU/EV PVC sampling
  - Concrete gutters
  - Retention tank
  - Traps
  - Drain
- Sealing
  - Waterproofing + Insulation
- Carpentry (inside and outside)
  - Curtain wall grid
  - Glass door
  - Full door 1 leaf
  - Full gate
  - chassis
  - Glazed partition
  - Grating tablecloth
  - Galvanized steel staircase
  - Wooden door
  - Full steel door
  - Wood skirting boards
  - Wood cladding wall, floor, ceiling
  - Galvanized steel poles
  - Galvanized steel beam
- Flattery
  - Distribution partition 72/48
  - Simple dubbing
  - Acoustic flocking
  - Placostil fire barriers
- Technical floor
  - Technical floor removable slabs
  - False hollow floor not removable
  - Coating + cylinders
  - Copper braid (grounding)
- Tiling
  - Protection under SEL tiles
  - Protection under SPEC tiles
  - tiling
  - Flexible coating
- Paint
- Lift

3.1.7.2.8. Data centre energy consumption breakdown

The 2019 energy consumptions of global data centre in Europe 28 and the breakdown per type of data centre have been extracted from the EU-Cloud Study (2019 is forecast).

Table 118 - Data centres' energy consumption breakdown

Type of data centre	Annual energy consumption TWh (2019)
Cloud Data Centre	29.8
Traditional Data Centre	47.9
Edge Data Centre	2.2
TOTAL	**79.98**

4. Contextualisation of the results

The results of this study can be compared to literature to determine the potential differences and similarities. Thus, it is important to note that such a comparison is limited because of the multiple differences between studies regarding the criteria considered, as well as geographical, technical, and temporal boundaries.

- **Regarding the criteria considered:** Most studies focus on the primary energy consumption, final energy consumption and climate change.
- **Regarding geographical boundaries:** most study does not have the same geographical perimeter (e.g. world, or a country),
- **Regarding technical boundaries:** technical perimeter (accounting for offices, maintenance, etc.) or methodological perimeter (accounting for renewable energy or not), can vary depending on the scope considered.
- **Regarding temporal boundaries:** It is important to note that the reference year is not always 2019: as there are fast evolution in the digital services sector, this can lead to differences.

The extrapolation to EU-28 has been performed based on the GDP. It is important to note that the electricity mixes used for the different geographical zones are different, leading to discrepancies except for the final use consumption indicator.

Those comparisons are thus only allowing to situate the present study in the existing background.

Table 119 - Comparison to other studies – Original study perimeter

			IMPACTS FOR THE STUDY PERIMETER											
Study	Year	Perimeter	Climate change - kg CO2 eq.				Primary energy consumption - MJ				Final energy consumption (use) - MJ			
			Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
[1] Present study	2019	EU-28	1.21E +11	2.21E +10	4.18E +10	1.85E +11	2.46E +12	6.58E +11	1.11E +12	4.23E +12	5.48E +11	1.83E +11	2.88E +11	1.02E +12
[2] "Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market", 2020, Environment Agency Austria & Borderstep Institute[i]	2018	EU-28											2.76E +11	
[3] "The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015", 2018, J. Malmodin, D. Lundén[ii], adapted to EU-28 and 2020 by J. Malmodin	2020	EU-28	1.0E +11	1.25E +10	1.20E +10	1.3E +11								7.2E +11
[4] "Empreinte environnementale du numérique mondial", 2019, greenIT.fr[iii]	2019	World	8.82E +11	3.08E +11	2.10E +11	1.4E +12	1.47E +13	5.63E +12	4.16E +12	2.45E +13	2.06E +12	1.50E +12	1.12E +12	4.68E +12
[5] "Assessing ICT global emissions footprint: Trends to 2040 & recommendations", 2018, Lotfi Belkhir, Ahmed Elmeligi[iv]	2017	World	Min: 9.45E +11 Max: 1.25E +12 Avr: 1.10E +12	2.03E +11	3.52E +11	Min: 1.5E +12 Max: 1.8E +12 avr: 1,65E +12								
[6] "Impacts environnementaux du numérique en France", 2020, greenIT.fr[v]	2020	France	2.02E +10	2.40E +09	1.44E +09	2.4E +10	4.15E +11	1.36E +11	9.72E +10	6.48E +11				

[i] Hintemann, R., Hinterholzer, S., Montevecchi, F., & Stickler, T. (2020). Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Borderstep Institute & Environment Agency Austria. Available at: <https://digital-strategy.ec.europa.eu/en/library/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market> [Accessed 30 September 2021].

[ii] Malmodin, J. and Lundén, D., 2018. The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015. Sustainability, [online] 10(9), p.3027. Available at: <https://www.mdpi.com/2071-1050/10/9/3027/htm> [Accessed 30 September 2021].

[iii] GreenIT.fr, 2020. The environmental footprint of the digital world. [online] Available at: <https://www.greenit.fr/wp-content/uploads/2019/11/GREENIT_EENM_etude_EN_accessible.pdf> [Accessed 30 September 2021].

[iv] Belkhir, L. and Elmeligi, A., 2018. Assessing ICT global emissions footprint: Trends to 2040 & recommendations. Journal of Cleaner Production, [online] 177, pp.448-463. Available at: <https://www.semanticscholar.org/paper/Assessing-ICT-global-emissions-footprint%3A-Trends-to-Belkhir-Elmeligi/c85484e0074fd774e1e1b026a16d4ed92a2bc23b> [Accessed 30 September 2021].

[v] GreenIT.fr, 2020. Impacts environnementaux du numérique en France. [online] GreenIT.fr. Available at: <https://www.greenit.fr/wp-content/uploads/2020/06/2020-06-iNum-etude-impacts-numerique-France-rapport.pdf> [Accessed 30 September 2021].

Table 120 - Comparison to other studies – EU-28 perimeter

Study	Year	Perimeter	IMPACT FOR EU-28 PERIMETER (EXTRAPOLATION, IN PERCENTAGE OF THE PRESENT STUDY)											
			Climate change - kg CO2 eq.				Primary energy consumption - MJ				Final energy consumption (use) - MJ			
			Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
[1] Present study	2019	EU-28	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
[2] "Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market", 2020, Environment Agency Austria & Borderstep Institute[i]	2018	EU-28											95.8%	
[3] "The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015", 2018, J. Malmodin, D. Lundén[ii], adapted to EU-28 and 2020 by J. Malmodin	2020	EU-28	82.6%	56.6%	28.7%	70.3%								70.6%
[4] "Empreinte environnementale du numérique mondial", 2019, greenIT.fr[iii]	2019	World	129.8%	248.9%	89.7%	135.1%	106.5%	152.0%	66.8%	103.3%	67.2%	146.4%	69.4%	81.9%
[5] "Assessing ICT global emissions footprint: Trends to 2040 & recommendations", 2018, Lotfi Belkhir, Ahmed Elmeligi[iv]	2017	World	162.0%	163.8%	150.2%	158.9%								
[6] "Impacts environnementaux du numérique en France", 2020, greenIT.fr[v]	2020	France	95.9%	62.4%	19.8%	74.6%	97.2%	119.0%	50.5%	88.2%				

[i] Hintemann, R., Hinterholzer, S., Montevecchi, F., & Stickler, T. (2020). Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Borderstep Institute & Environment Agency Austria. Available at: <https://digital-strategy.ec.europa.eu/en/library/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market> [Accessed 30 September 2021].

[ii] Malmodin, J. and Lundén, D., 2018. The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015. Sustainability, [online] 10(9), p.3027. Available at: <https://www.mdpi.com/2071-1050/10/9/3027/htm> [Accessed 30 September 2021].

[iii] GreenIT.fr, 2020. The environmental footprint of the digital world. [online] Available at: <https://www.greenit.fr/wp-content/uploads/2019/11/GREENIT_EENM_etude_EN_accessible.pdf> [Accessed 30 September 2021].

[iv] Belkhir, L. and Elmeligi, A., 2018. Assessing ICT global emissions footprint: Trends to 2040 & recommendations. Journal of Cleaner Production, [online] 177, pp.448-463. Available at: <https://www.semanticscholar.org/paper/Assessing-ICT-global-emissions-footprint%3A-Trends-to-Belkhir-Elmeligi/c85484e0074fd774e1e1b026a16d4ed92a2bc23b> [Accessed 30 September 2021].

[v] GreenIT.fr, 2020. Impacts environnementaux du numérique en France. [online] GreenIT.fr. Available at: <https://www.greenit.fr/wp-content/uploads/2020/06/2020-06-iNum-etude-impacts-numerique-France-rapport.pdf> [Accessed 30 September 2021].

Final energy consumption

A first comparison can be made on the final energy consumption (use) indicator. Indeed, this indicator is independent of the electricity mix used, and therefore is more consistent between studies having different localisations (even though other factors vary between localisation, such as IT equipment rate).

The present study has slightly higher results for the total, compared to the other studies. This can be partly explained by some discrepancies in the parameters considered, which is the case for user equipment consumption, for example between the present study and study [4]: as consumption patterns are different from a region to another, the time spent using an end-user device per day is different in the EU-28 and worldwide. For example, this study uses a frequency of use of laptops of 3.56 hours/day, based on European consumption patterns, while the study [4] uses a worldwide frequency of use of 0.5 hours/day.

Compared to study [4], impacts are higher for the tiers 3 due to a more precise characterisation of datacentres specifically for the EU. The impacts of tier 2 are lower, due to the use of more recent data (data from 2015 or prior tended to consider an increased in network consumption, while a decreased finally occurred).

Primary energy consumption

The primary energy consumption was only available for the studies [4] and [6]. The primary energy consumption varies similarly to the final energy consumption for the two studies ([4] and [6]). Indeed, those two studies have been performed with the same methodology, and therefore have the same profile of impact. Values for tier 1 are similar to the present study despite having a more restrictive perimeter due to the use of older data for equipment manufacturing (manufacturers improve production efficiency over time, leading to a decrease of impact for similar equipment over time).

However, primary energy consumption results show more contrasted results for tiers 2 and 3. For tier 2, this can be explained by a very different methodology applied to assess the impacts of networks in this study. A classical life cycle analysis assesses the environmental impacts using the lifespan of the equipment to analyse and considering the stock of equipment in place in the scope of the study. Here, another approach was used: considering that the lifespan of network IT equipment is very long compared to the lifespan of end-user IT equipment, but even more, hard to estimate, the approach taken in the present study is based on the inventory of the network equipment implemented during a given year (2020) considering it is more representative of the environmental impacts of the network today than the stock of network equipment implemented with for some of them a lifespan of more than 20 or 30 years. This difference in the approach of tier 2 may explain why primary energy consumption is lower in the present study than in studies [4] and [6], which are based on an inventory.

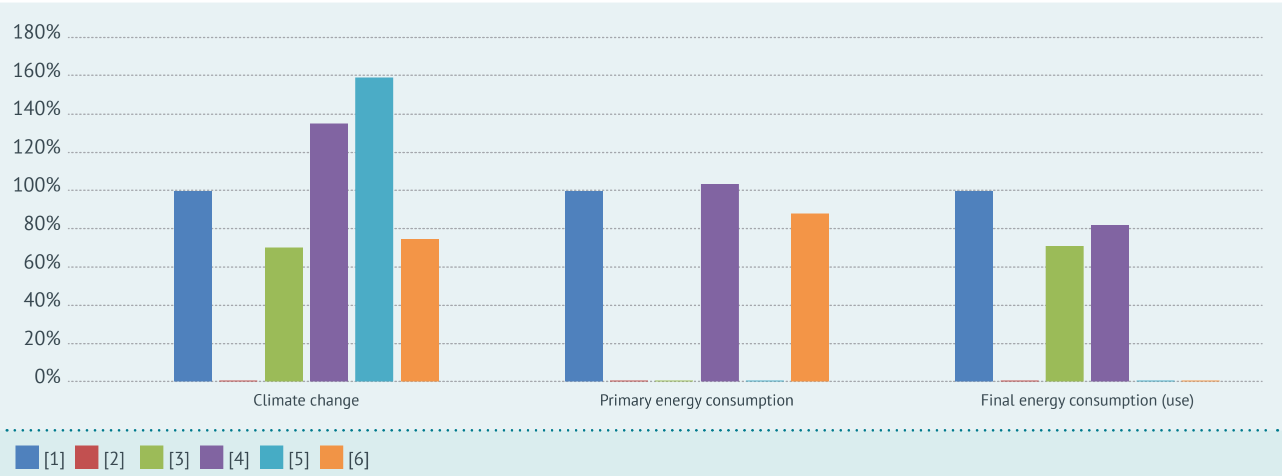
Regarding primary energy consumption for tier 3, this study shows higher results than the one of studies [4] and [6]. This difference may be explained by the geographical differences in the perimeter of the studies, assuming there is proportionally more servers in the EU per GDP point than globally per GDP point (study [4]); and slightly more in the EU per GDP point than in France per GDP point (study [6]).

Contribution to climate change

The global warming impact is more difficult to interpret, as the electricity mix is different for each location. The results are within the same range (from 75% to 159%), with the present study being in the lower-part of impacts due to an EU-28 electricity mix less carbon-intensive than the world average, at the exception of study [6] which is on France perimeter, with a low-carbon electricity mix which is neither representative of the EU-28 electricity mix nor the global electricity mix.

Compared to study [3], impacts are slightly higher for the tier 1, and much higher for tier 2 and 3. The discrepancies can be explained both with the different perimeter of tiers (for example, CPE are accounted for in end-user equipment and not in networks), and with the use of a different sources to estimate the number of servers, the proportion of cloud vs traditional data centres and the consumption of data centres (Borderstep method and Malmodin method).

Figure 9 - Comparison to literature – Global – Comparison between studies



5.Appendices

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Acronyms

2G: second-generation cellular network

3G: third-generation cellular network

4G: fourth-generation cellular network

5G: fifth-generation cellular network

ADP: abiotic depletion potential

ADSL: Asymmetric Digital Subscriber Line

AI: Artificial Intelligence

ATM: Automated teller machine

BBU: BaseBand Unit

BTS: Base Transceiver Station

CC-BY-SA: Creative Commons - Attribution - ShareAlike

CFC: Chlorofluorocarbon

CFF: circular footprint formula

CML: Institute of Environmental Sciences of the Faculty of Science of Leiden University

CML: the methodology of the Centre for Environmental Studies (CML)

of the University of Leiden

CO2: Carbon dioxide

CPE: Customer Premise Equipment

CPU: Central processing unit

CTUe: comparative toxic unit ecotoxicity : expresses the estimated potentially affected fraction of species (PAF) integrated over time and the volume of the freshwater compartment

CTUh: comparative toxic unit human : expresses the estimated increase in morbidity (the number of disease cases) in the total human population

DNS: Domain Name System

DSLAM: Digital Subscriber Line Access Multiplexer

DVD: Digital Video Disc

EB: Exabyte

EFA: European Free Alliance

EoL: End of Life

eq.: equivalent

ETSI: European Telecommunications Standards Institute

EU: European Union

EU-28: European Union (including 28 members)

FTTx: Any of various fiber to the [destination], such as FTTP (Ffiber to the premises), fiber to the home (FTTH) and fiber to the building (FTTB)

FW: FireWall

GAFAM: Google Amazon Facebook Apple Microsoft

GB: Gigabyte

GDP: Gross domestic product

GGSN: Gateway GPRS Support Node

GHG: Greenhouse gas

Gi: Gateway-Internet

GPRS: General Packet Radio Service

GPS: Global Positioning System

GPU: Graphics processing unit

GtCO2 eq.: GigaTonne of Carbon dioxide equivalent

GWP: Global warming potential

HDD: Hard disk drive

HLR: Home Location Register

HPC: Hyperscale Computers

HSP: Hardware Specification Level

HSS: Home Subscriber Server

IAD: Integrated Access Device

ICT: Information and communications technology

IDU: InDoor Unit

ILO: International Labour Organisation

IoT: Internet of Things

IPCC: Intergovernmental Panel on Climate Change

ISO: International Organization for Standardization

IT: Information technology

ITU: International Telecommunication Union

JRC: Joint Research Centre

kBq: kilobecquerel

kg: kilogram

km: kilometres

KPI: Key performance indicator

kWh: KiloWatt-hour

LAN: Local Area Network

LCA: Life cycle assessment

LCD: Liquid-Crystal Display

LCI: Life cycle inventory analysis

LCI: Life cycle inventory analysis

LCIA: Life cycle impact assessment

LCIA: Life cycle impact assessment

LCIE CODDE Bureau Veritas: In French: Laboratoire Central Industries Electriques, COnception Développement Durable Environnement, Bureau Veritas, in English: Central Electrical Industries Laboratory, Sustainable Development Environment Design, Bureau Veritas

LED: Light-Emitting Diodes

MFD: Main Distribution Frame

MJ: Mega Joule

MME: Mobility Management Entity

mol H+ eq.: mole of hydron equivalent. A hydron is an atom of hydrogen without electron, also known as a proton. It plays an important role in acid-based chemical reactions

MP3: MPEG-1 Audio Layer III or MPEG-2 Audio Layer III

MSP: Managed Services Providers

MT: Mega Tonne

NMVOC: Non-methane volatile organic compound

OAN: Optical Access Node

ODU: OutDoor Unit

OLED: Organic Light-Emitting Diodes

OLT: Optical Line Termination

ONT: Optical Network Termination

OS: Operating System

PCB: Process control block

PCRF: Policy and Charging Rules Function

PEF: Product Environmental Footprint

PEFCR: Product Environmental Footprint Category Rules

PJ: Peta Joule

POS: Point Of Sale

PSTN: Public Switched Telephone Network

pt: points

PUE: Power Usage Effectiveness

QLED: Quantum-dot Light-Emitting Diodes

R&D: Research & Development

ReCiPe: Remote Encryptor Configuration Information Protocol

RF: Radio Frequency

RFID: Radio Frequency IDentification

RRH: Remote Radio Head

RRU: Remote Radio Unit

Sb: Stibium, latin name of Antimony

SD: Secure Digital

SFP: Small Form-factor-Pluggable

SGSN: Serving GPRS support node

SP-GW: Serving/PDN-Gateway

SSD: Solid-state drive

SUV: Sport utility vehicle

T: Tonne (metric)

TSMC: Taiwan Semiconductor Manufacturing Company

TV: Television

TWh: TeraWatt-hour

U235: Uranium-235

UPS: Uninterruptible Power Supply

USA: United States of America

USB: Universal Serial Bus

W: Watt

WDM: Wavelength Division Multiplexing

WEEE: Waste Electrical and Electronic Equipment, also known as e-waste

WLAN: Wireless LAN

WMO: World Meteorological Organisation

xDSL: Any of various digital subscriber line technologies, such as ADSL (Asymmetric Digital Subscriber Line), HDSL (High-bit-rate digital subscriber line), and VDSL (Very high-speed digital subscriber line)

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