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DIGITAL TECHNOLOGIES IN EUROPE: an environmental life cycle approach

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Authors in alphabetical order:

Sofia Benqassem/Frederic Bordage/Lorraine de Montenay/Julie Delmas-Orgelet/ Firmin Domon/Etienne Lees Perasso/Damien Prunel/Caroline Vateau

Table of content

The authors (1/2)

This study was prepared under the direction of Frédéric Bordage, founder of GreenIT.fr.

The project management of the study was headed by Lorraine de Montenay, independent consultant and member of the collective GreenIT.fr.

The life cycle assessment (LCA) was carried out by Etienne Lees-Perasso and Damien Prunel of LCIE CODDE Bureau Veritas, with contributions from Caroline Vateau, and Sofia Benqassem of Neutreo by APL Data centre, Lorraine de Montenay, independent consultant & member of GreenIT.fr, Frédéric Bordage, founder of GreenIT.fr and Julie Orgelet, independent consultant at DDemain.

Frédéric Bordage greenIT.fr

Since 2004, GreenIT.fr has brought together experts in digital sobriety, green IT, sustainable ICT, and the eco-design of digital services. For more than 17 years, GreenIT.fr has created methodologies, benchmarks for evaluation, sets of best practices, benchmarks, and other tools. As a group of experts, GreenIT.fr advises public authorities and large organizations and carries out public benchmarks and studies based on a standard LCA methodology.

Our mindset: the highest level of expertise available in France and in Europe; constructive and without dividing lines; strong commitment to the subject; apolitical.

Lorraine de Montenay ion conseil

As an independent consulting brand, Ion conseil accompanies organisations in their responsible digital projects and transformations. Ion conseil supports managers, teams and individuals from the definition of needs through to implementation. Our common goal: to build an efficient, organisation of human dimensions and resilient to change, while reducing its environmental footprint.

As a member of GreenIT.fr, she participates in the dissemination of digital sobriety expertise and best practices.

The authors (2/2)



Etienne Lees-Perasso | Damien Prunel | Firmin Domon

Bureau Veritas LCIE is the ecodesign and LCA centre of expertise for Bureau Veritas Group, with 20 years of experience. Our company has built up partnerships with numerous companies in different sectors such as Electronic and Electrical Equipment, digital services, textile, hard-line, food industry, and furniture.

Bureau Veritas LCIE is part of Bureau Veritas Group, a world-leading professional services company. We offer solutions to help organisations achieve, maintain and demonstrate compliance with quality, health, safety, environmental and social accountability obligations.


Caroline Vateau | Sofia Benqassem

Created in 1983, APL DATA CENTER is the leading consulting and engineering firm specialised in the design and construction of data centres in France.

Our sustainable IT department is involved in the development of methodologies and standards to assess environmental impact using LCA methodologies and assists the digital players in reducing their environmental footprint.

Our areas of expertise: environmental audit and eco-design, green IT strategy, certification support (30 standards), training and communication.

Julie Orgelet

As an experienced LCA consultancy, DDemain contributes to the pragmatic and efficient application of LCA in the field of digital services.

The proper appropriation and application of LCA results are at the heart of DDemain's work. As an independent expert, DDemain has developed training and skills transfer to allow the ecosystem of digital service LCA practitioners to grow.

Foreword

The first quarter of the 21st century marked an unprecedented surge in reports of forest fires, floods and extreme weather events. It is clear that our current development model has reached its limit and now poses a direct threat to our civilisation and planet. Scientific reports are becoming increasingly precise and alarming.

A constant and uncontrolled increase in our greenhouse gas emissions will make our reality one of cataclysmic and irreversible climate change.

Biodiversity is under unparalleled attack, with the sixth mass extinction underway. In the Anthropocene era, the evidence that our "extractivist" industrial model and our "consuming" society disrupt the Earth's natural cycles is indisputable. We need to take action.

This study highlights the resounding impact of digital technology and the IT sector on our environment. It deconstructs the notion that the digital world is light and dematerialised - "virtual", "in the clouds" - and that it has no impact on the physical world.

The COVID-19 pandemic has highlighted the European Union's heavy dependence on critical resources for the production of our digital devices. This is not just an environmental threat, but is precarious for the EU's digital sovereignty. How can we ensure our digital resilience for the times to come?

A systemic approach to change is fundamental. The industrial revolution saw a tenfold increase in humanity's mechanical and energy capacity, but brought with it an environmental sacrifice that has taken us centuries to fully comprehend. The digital revolution will bring about equally fundamental changes - be they ecological, social, economic, democratic or geopolitical. We need to ensure that we do not usher in a similar Trojan horse.

Data will be key to ensuring that the digital and climate transitions do not hamper each other. Knowing the exact environmental cost of technology is a prerequisite for green digital innovation. In order to make strong policy decisions for the future, we urgently need to assess the ecological impact of digital technology and its contribution to the European Green Deal. This must be backed up by action in European legislation: we need environmental standards for digital technologies, networks and infrastructures for their entire life cycle and condition our digital strategic decisions to their cost/benefits in terms of environmental impact.

The European Commission, under the presidency of Ursula Von der Leyen, has declared its ambition to adapt the European economy to the urgency of our time with its flagship policies, the European Green Deal and Europe Fit for the Digital Age. Reconciling the dual ecological and digital transitions will be an essential pillar of future EU legislation.

Accurately assessing the impact of our digital technology will encourage sustainable digital innovation. This is the best way to ensure that digital advancement stays in line with the European Green Deal.

A European approach is essential to achieving a green and sustainable digital economy. We hope that this study will help lay the evidence-based foundations for the urgent political decisions that we must take to meet the challenges of our time.

David Cormand & Kim van Sparrentak

Disclaimer

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2. Abstract

2.1—Abstract to policy-makers

The IPCC summary for policymakers published on 9 August 2021, confirms that "*global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades*"[1]. The same report states clearly that "*every tonne of CO_2 emissions adds to global warming*"[2] and that "*this relationship implies that reaching net zero anthropogenic CO_2 emissions is a requirement to stabilize human-induced global temperature increase at any level, but that limiting global temperature increase to a specific level would imply limiting cumulative CO_2 emissions to within a carbon budget*"[3].

This means that in order to respect the Paris Agreement "*[to hold] the increase in global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels*"[4], every sector of human activity must contribute to limiting and reducing CO_2 and other greenhouse gas emissions.

In this context, the aim of this study was to assess the environmental impacts of information and communications technology (ICT) at the scale of the European Union (EU) for policy-makers and public knowledge, and provide:

1. An understanding of clear, updated data on the environmental impact of the ICT at the scale of Europe (EU-28).

2. A robust, objective and science-based methodology and calculation of the environmental impacts of ICT, based on a Life cycle Analysis (LCA).

3. Policy recommendations for digital development compatible with the Green Deal.

This study is a **multicriteria life cycle assessment**. This assessment in compliance with ISO 14040:2006 and ISO 14044:2006, with normalisation to allow comparison with planetary boundaries.

The multicriteria life cycle assessment makes it possible to depict the environmental impacts of ICT for the European Union (28, including UK[5]), for the year 2019, based on the following four life cycle phases:

1. Manufacturing phase: from extraction of the raw materials to the last factory gate

2. Distribution phase: from the last factory gate to the user

3. Use phase: impacts related to use, mainly electricity consumption

4. End-of-life phase: treatment, recycling, incineration and/or landfill of waste

Initially, 19 impact indicators were selected, based on the European Union Product Environmental Footprint methodology. To make them as comprehensible as possible and to focus our recommendation on appropriate topics, the most important indicators were selected. After normalisation and weighting, eight environmental impact indicators were selected as being the most important for digital services, representing 80 per cent of the global weighted results.

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1 IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press. P.18
2 *Ibid*, P.38
3 *Ibid*, P.39
4 "*Paris Agreement, FCCC/CP/2015/L.9/Rev.1*" (PDF). UNFCCC secretariat. Archived (PDF) from the original on 12 December 2015.
5 The UK was included in the scope of the EU for this study as UK was part of the EU in 2019.

The normalised and weighted results are the following:

Table 1—Normalised and weighted results

Resource use, minerals and metals - kg Sb eq.	22.9%
Resource use, fossils- MJ	17.0%
Acidification - mol H+ eq.	4.5%
Ecotoxicity, freshwater - CTUe	4.7%
Climate change - kg CO_2 eq.	16.2%
Ionising radiation, human health - kBq U235 eq.	11.1%
Particulate matter - Disease occurrence	4.0%
Photochemical ozone formation - human health - kg NMVOC eq.	1.8%

Four additional flow indicators were added to provide better comprehension of flows of material, waste and energy related to digital services:

Table 2—Flow indicators added

Raw materials - kg
Waste production - kg
Primary energy consumption - MJ
Final energy consumption (use) - MJ

Overall EU-28 digital services impacts were then assessed as follows:

Table 3—Overall impacts of EU-28 digital services (environmental impacts & flow indicators)

		Percentage of EU-28 boundaries per indicator
Resource use, minerals and metals - tonnes Sb eq.	5,760	39.3%
Resource use, fossils- PJ	3,960	26.4%
Acidification - mol H+ eq. (in billions)	1.19	1.8%
Ecotoxicity, freshwater - CTUe	3,090	35.2%
Climate change - Mt CO_2 eq.	185	40.7%
Ionising radiation, human health - GBq U235 eq.	278	0.8%
Particulate matter - Disease occurrence	8,000	23.2%
Photochemical ozone formation - human health - tonnes NMVOC eq.	464,000	1.7%
Raw materials - Mt	571	
Waste production - Mt	116	
Primary energy consumption - PJ	4,230	
Final energy consumption (use) - PJ	1,020	

Note: *due to the imprecision of data, land use and water consumption impacts have not been calculated.*

The equivalences are as follows:

- Resource use, mineral and metals is equivalent to 111t of gold in terms or rarity, and 571 Mt of displaced materials, equivalent to the weight of 9.20 billion humans (averaging 62 kg). This means that each year, the displaced materials related to EU-28 digital services roughly equal the weight of all human beings.
- Climate change impacts are similar to 370,000 round trips of a 500-passenger-equivalent plane between Paris and New York, or about 63 years of the actual connection (16 planes per day).
- Waste production is equal to the weight of 1.87 billion humans (averaging 62 kg).
- Electricity consumption is equal to 32,344,000 heaters (1,000 W) powered non-stop for a year.

In addition, at the EU-28 scale:

- Total electricity consumption for digital services in Europe is 283 TWh out of a total of 3,054 TWh[6], which means that electricity consumption for digital services during the use phase accounts for 9.3% of European electricity consumption.
- Total GHG emissions for digital services in Europe are 185 Mt CO_2 eq. out of a total of 4,378 Mt CO_2 eq.[7], which means that GHG emissions from digital services account for 4.2% of European GHG emissions.

Note

The EU-28 scale comparisons are aimed at providing a scale of related impacts and must not be understood as absolute results. The perimeters are different: some emissions related to digital services in the EU-28 occur outside EU-28 and are considered within the scope of the study (manufacturing of the devices); while the total emissions considered for the EU by the IEA are only emissions occurring within EU borders.

To learn more about imported emissions: https://www.idhsustainabletrade.com/news/hidden-CO2-emissions-europes-imported-responsibility/

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6 IEA. 2021. *Data & Statistics - IEA.* [online] Available at: <https://www.iea.org/data-and-statistics/data-browser?country=EU28&fuel=Electricity%20and%20heat&indicator=TotElecCons> [Accessed 30 September 2021].

7 EEA. 2021. *Data viewer on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU Member States).* [online] Available at: <https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer> [Accessed 30 September 2021].

The calculations for one EU-28 inhabitant are:

Table 4—Digital services impacts per EU-28 inhabitant (environmental impacts & flow indicators)

Resource use, minerals and metals - g Sb eq.	11.2
Resource use, fossils- MJ	7,710
Acidification - mol H+ eq.	2
Ecotoxicity, freshwater - CTUe	6,010
Climate change - kg CO_2 eq.	361
Ionising radiation, human health - kBq U235 eq.	541
Particulate matter - Disease occurrence	0.00156%
Photochemical ozone formation - human health - kg NMVOC eq.	0.91
Raw materials - kg	1,110
Waste production - kg	225
Primary energy consumption - MJ	8,230
Final energy consumption (use) - MJ	1,980

For one European, this is equivalent to one year of the following:

- Climate change impacts are similar to 1 round trip by a plane passenger between Paris and Athens.
- Resource use, mineral and metals: 0.69 kg of tin in terms or rarity, and 1,110 kg of displaced materials, equivalent to the weight of 18 humans (averaging 62 kg).
- Waste production: 225 kg of global waste, equivalent to the weight of 3.6 humans (averaging 62 kg).
- Electricity consumption: 1 heater (1,000W) powered non-stop for 23 days.

The results highlight the need to consider multiple environmental impact categories with regard to ICT in climate & environmental strategies and for policy-making.

The life cycle assessment is divided into three tiers[8], which provides a broad view of ICT environmental impacts on a large scale:

- **Tier 1:** End-user equipment (laptops, phones, screens, TVs, printers, etc.)
- **Tier 2:** Networks (fixed, mobile, core)
- **Tier 3:** Data centres (from large hyperscale data centres to small company servers)

The principal results show the following breakdown of environmental impacts per tier:

Table 5—Breakdown of EU-28 digital services impacts per tier (environmental impacts & flow indicators)

	Tier 1 End user devices	Tier 2 Network	Tier 3 Data centres
Resource use, minerals and metals	88.8%	5.9%	5.3%
Resource use, fossils	62.0%	14.1%	23.9%
Acidification	65.8%	12.1%	22.1%
Ecotoxicity, freshwater	69.4%	10.1%	20.5%
Climate change	65.5%	11.9%	22.5%
Ionising radiation, human health	65.5%	14.4%	20.2%
Particulate matter	64.0%	13.0%	22.9%
Photochemical ozone formation - human health	67.3%	11.4%	21.3%
Raw materials	66.7%	12.2%	21.2%
Waste production	78.6%	8.6%	12.8%
Primary energy consumption	58.2%	15.6%	26.2%
Final energy consumption (use)	53.8%	17.9%	28.2%

Key findings

I. "Resource use, minerals and metals" is by far the most important environmental indicator regarding the environmental impacts of ICT, before "Climate change" and "Resource use, fossils". This means multicriteria assessments are key to providing a systemic overview of the environmental impacts and avoiding impact transfers.

II. The manufacturing phase is the category with the greatest impact on "resource use, minerals and metals", and the raw material and waste production indicators.

The use phase is the category with the greatest impact on the other indicators at the scale of Europe.

III. The end-user devices are the most impactful, representing between 90% and 54% of the impacts, depending on the indicator. This is due to the large number of devices in all categories.

IV. The TV category alone represents a large proportion of the environmental impacts on all the indicators assessed, especially "Resource use, minerals and metals" (20%) for environmental indicators and waste production (21.5%) for flow indicators.

V. Although the "IoT connected objects" category contains a miscellany of devices and configurations, the rise of the IoT is noticeable, especially regarding final energy consumption.

8 Full methodology is detailed in the Methodology chapter

VI. Many device categories, such as desktops, laptops, TV boxes, smartphones, printers, desktops game consoles and tablets, are important contributors to the environmental impacts of ICT end-user devices.

VII. The datacentre tier contributes between 5% and 23% of the environmental impact of ICT according to the environmental indicators, and accounts for between 13% and 28% of the flows.

We observe an inversion of "trends" between the most impactful environmental indicators for ICT, climate change and resource use (minerals and metals). This shows that climate change cannot be effectively mitigated without at the same time addressing the other environmental issues related to an activity such as ICT. This is to be understood in the light of technology resource dependency: each specific non-renewable resource used can become a separate issue in its own right in the case of a flow shortage or if a material becomes scarce.

In view of the results, it seems that in the EU-28, ICT already benefits to some extent from renewables in the electrical energy mix. However, regarding the resources used for the manufacturing phase, contradictory interests are at play in the use of the minerals and metals resources needed on one hand for ICT manufacturing and on the other for technologies needed for the ecological transition, which represent much greater demand quantitatively, demand which is set to grow steeply in the coming years[9] (e.g. for batteries for electrical vehicles or solar photovoltaic panels). Looking at the environmental impact with regard to resources, there are physical limits that cannot be exceeded, in a sector of activity where recycling is only partially possible.

Data transparency

Despite the many possibilities offered by the Internet and data computing today, it is still very difficult to obtain freely accessible and reliable data to make a perfectly robust inventory. As far as possible and within the time limits of the study, this study used the best information available, and wherever possible, public information. We have observed frequent difficulties in making a robust estimate of a certain number of equipment or infrastructure items that make up the inventory. In accordance with the iterative logic of the ISO-14040-44 standard, this study is to be repeated to progressively be more accurate and limit uncertainties.

In view of the collective interest of opening up such information for measuring environmental impacts and informing decision-making, and for more effective measurement and reduction of the environmental impacts more effectively, we urge the different public and private stakeholders to address this question to allow Europeans but also, more globally, the citizens of the world to access robust research through greater transparency.

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9 2019. *Global Material Resources Outlook to 2060: Economic Drivers And Environmental Consequences.* [ebook] OECD. Available at: <https://www.oecd.org/environment/waste/highlights-global-material-resources-outlook-to-2060.pdf> [Accessed 30 September 2021].

2.2—Abstract for the general public

Human activities are impacting and polluting the environment in many ways (climate change, biodiversity loss, ocean acidification, human health, etc.). For more than thirty years, scientists have evaluated and confirmed the various impacts of human activities on the environment, with increasingly urgent warnings with regard to climate change in particular, which is human-induced. In 2016, the European Union signed the Paris Agreement with 190 other States, committing itself to "*holding the increase in global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels*"[10].

Each sector of human activity is concerned when it comes to limiting and reducing CO_2 and other greenhouse gas emissions in order to mitigate climate change. To do so, it is also important not only to consider climate change, but also to reduce other environmental impacts and avoid pollution transfers.

In this context, the aim of this study was to assess the environmental impacts of information and communications technology (ICT) at the scale of the European Union (EU) for policy-makers and public knowledge, and provide:

1. Clear, updated data on the environmental impact of ICT at the European scale (EU-28);

2. A robust, objective and science-based methodology and calculation of the environmental impacts of ICT, based on a Life Cycle Analysis (LCA);

3. Policy recommendations for digital development compatible with the Green Deal.

This study is a **multicriteria life cycle assessment**. This assessment tends toward compliance with ISO 14040:2006 and ISO 14044:2006, with normalisation to allow comparison with planetary boundaries.

The multicriteria life cycle assessment makes it possible to describe the environmental impacts of ICT for the European Union (28, including UK[11]) for the year 2019, based on the following four life cycle phases:

1. Manufacturing phase: from extraction of the raw materials to the last factory gate

2. Distribution phase: from the last factory gate to the user

3. Use phase: impacts related to use, mainly electricity consumption

4. End-of-life phase: treatment, recycling, incineration and/or landfill of waste

Initially, 19 impact indicators were selected, based on the European Union Product Environmental Footprint methodology. To make them as comprehensible as possible and to focus our recommendation on appropriate topics, the most important indicators were selected. After normalisation and weighting, eight environmental impact indicators were selected as being the most important for digital services, representing 80% of the global weighted results.

The normalised and weighted results are as follows:

Table 6—Normalised and weighted results

Resource use, minerals and metals - kg Sb eq.	22.9%
Resource use, fossils- MJ	17.0%
Acidification - mol H+ eq.	4.5%
Ecotoxicity, freshwater - CTUe	4.7%
Climate change - kg CO_2 eq.	16.2%
Ionising radiation, human health - kBq U235 eq.	11.1%
Particulate matter - Disease occurrence	4.0%
Photochemical ozone formation - human health - kg NMVOC eq.	1.8%

Four additional flow indicators were added to provide better comprehension of flows of material, waste and energy related to digital services:

Raw materials - kg
Waste production - kg
Primary energy consumption - MJ
Final energy consumption (use) - MJ

10 "*Paris Agreement, FCCC/CP/2015/L.9/Rev.1*" (PDF). UNFCCC secretariat. Archived (PDF) from the original on 12 December 2015.
11 The UK was included in the scope of the EU for this study as UK was part of the EU in 2019.

Global EU-28 digital services impacts were then assessed as follow:

Table 7—Overall impacts of EU-28 digital services impacts (environmental impacts & flow indicators)

Resource use, minerals and metals - tonnes Sb eq.	5,760
Resource use, fossils- PJ	3,960
Acidification - mol H+ eq. (in billions)	1.19
Ecotoxicity, freshwater - CTUe	3,090
Climate change - Mt CO_2 eq.	185
Ionising radiation, human health - GBq U235 eq.	278
Particulate matter - Disease occurrence	8,000
Photochemical ozone formation - human health - tonnes NMVOC eq.	464,000
Raw materials - Mt	571
Waste production - Mt	116
Primary energy consumption - PJ	4,230
Final energy consumption (use) - PJ	1,020

In addition, at the EU-28 scale:

- Total electricity consumption for digital services in Europe is 283 TWh out of a total of 3,054 TWh[12], which means that electricity consumption for digital services during the use phase accounts for 9.3% of European electricity consumption.
- Total GHG emissions for digital services in Europe are 185 Mt CO_2 eq. out of a total of 4,378 Mt CO_2 eq.,[13] which means that GHG emissions from digital services account for 4.2% of the European GHG emissions.

Note

The EU-28 scale comparisons are aimed at providing a scale of related impacts and must not be understood as absolute results. The perimeters are different: some emissions related to digital services in the EU-28 occur outside EU-28 and are considered within the scope of the study (manufacturing of the devices); while the total emissions considered for the EU by the IEA are only emissions occurring within EU borders.

To learn more about imported emissions: https://www.idhsustainabletrade.com/news/hidden-CO_2-emissions-europes-imported-responsibility/

The calculations for one EU-28 inhabitant are:

Table 8—Digital services impacts per EU-28 inhabitant (environmental impacts & flow indicators)

Resource use, minerals and metals - g Sb eq.	11.2
Resource use, fossils- MJ	7,710
Acidification - mol H+ eq.	2
Ecotoxicity, freshwater - CTUe	6,010
Climate change - kg CO_2 eq.	361
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Raw materials - kg	1,110
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The equivalences are as follows:

- Climate change impacts are similar to 1 round trip of a plane passenger between Paris and Athens.
- Resource use, mineral and metals: 0.69 kg of tin in terms or rarity, and 1,110 kg of displaced materials, equivalent to the weight of 18 humans (averaging 62 kg).
- Waste production: 225 kg of global waste, equivalent to the weight of 3.6 humans (averaging 62 kg).

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12 IEA. 2021. *Data & Statistics - IEA*. [online] Available at: <https://www.iea.org/data-and-statistics/data-browser?country=EU28&fuel=Electricity%20and%20heat&indicator=TotElecCons> [Accessed 30 September 2021].

13 EEA. 2021. *Data viewer on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU Member States).* [online] Available at: <https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer> [Accessed 30 September 2021].

- Electricity consumption: 1 heater (1,000W) powered non-stop for 23 days.

The results highlight the need to consider multiple environmental impact categories with regard to climate and environmental strategies and for policy-making regarding ICT.

The life cycle assessment is divided into 3 tiers[14], which provides a broad view of ICT environmental impacts on a large scale:

- **Tier 1:** End-user equipment (laptops, phones, screens, TVs, printers, etc.)
- **Tier 2:** Networks (fixed, mobile, core)
- **Tier 3:** Data centres (from large hyperscale data centres to small company servers)

Principal results showing the following breakdown of environmental impacts per tier:

Table 9 – Breakdown of impacts by tier

	Tier 1 End user devices	Tier 2 Network	Tier 3 Data centres
Resource use, minerals and metals	88.8%	5.9%	5.3%
Resource use, fossils	62.0%	14.1%	23.9%
Acidification	65.8%	12.1%	22.1%
Ecotoxicity, freshwater	69.4%	10.1%	20.5%
Climate change	65.5%	11.9%	22.5%
Ionising radiation, human health	65.5%	14.4%	20.2%
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Photochemical ozone formation - human health	67.3%	11.4%	21.3%
Raw materials	66.7%	12.2%	21.2%
Waste production	78.6%	8.6%	12.8%
Primary energy consumption	58.2%	15.6%	26.2%
Final energy consumption (use)	53.8%	17.9%	28.2%

Key findings

I. "Resource use, minerals and metals" is by far, the most important environmental indicator regarding the environmental impacts of ICT, before "Climate change" and "Resource use, fossils". This means multicriteria assessments are key to providing a systemic overview of the environmental impacts and avoiding impact transfers.

II. The manufacturing phase is the category with the greatest impact on "resource use, minerals and metals", and the raw material and waste production indicators.

The use phase is the category with the greatest impact on the other indicators.

III. The end-user devices are the most impactful, representing between 90% and 54% of the impacts, depending on the indicator. This is due to the large number of devices in all categories.

IV. The TV category alone represents a large proportion of the environmental impacts on all the indicators assessed, especially on "Resource used, minerals and metals" (20%) for environmental indicators and waste production (21.5%) for flow indicators.

V. Although the "IoT connected objects" category contains a miscellany of devices and configurations, the rise of the IoT is noticeable, especially regarding final energy consumption.

VI. Many device categories, such as desktops, laptops, TV boxes, smartphones, printers, desktops game consoles and tablets, are important contributors to the environmental impacts of ICT end-user devices.

VII. The datacentre tier contributes to between 5% and 23% of the environmental impact of ICT according to the environmental indicators, and accounts for between 13% and 28% of the flows.

We observe an inversion of "trends" between the most impactful environmental indicators for ICT, climate change and resource use (minerals and metals). This shows that climate change cannot be effectively mitigated without at the same time addressing the other environmental issues related to an activity such as ICT. This is to be understood in the light of technology resource dependency: each specific non-renewable resource used can become a separate issue in its own right in the case of a flow shortage or if a material becomes scarce.

14 Full methodology is detailed in the Methodology chapter

In view of the results, it seems that in the EU-28, ICT already benefits to some extent from renewables in the electrical energy mix. However, regarding the resources used for the manufacturing phase, contradictory interests are at play in the use of the minerals and metals resources needed on one hand for ICT manufacturing and on the other for green technologies, which represent much greater demand quantitatively, demand which is set to grow steeply in the coming years[15] (e.g. for batteries for electrical vehicles or solar photovoltaic panels). Looking at the environmental impacts on resources, there are physical limits that cannot be exceeded, in a sector of activity where recycling is only partially possible.

Data transparency

Despite the many possibilities offered by the Internet and data computing today, it is still very difficult to obtain freely accessible and reliable data to make a perfectly robust inventory. As far as possible and within the time limits of the study, this study used the best information available, and wherever possible, public information. We have observed frequent difficulties in making a robust estimate of a certain number of equipment or infrastructure items that make up the inventory. In accordance with the iterative logic of the ISO-14040-44 standard, this study is to be repeated to progressively be more accurate and limit uncertainties.

In view of the collective interest of opening up such information for measuring environmental impacts and informing decision-making, and for more effective measurement and reduction of the environmental impacts, we urge the different public and private stakeholders to address this question to allow Europeans but also, more globally, the citizens of the world to access robust research through greater transparency.

15 2019. *Global Material Resources Outlook to 2060: Economic Drivers And Environmental Consequences*. [ebook] OECD. Available at: <https://www.oecd.org/environment/waste/highlights-global-material-resources-outlook-to-2060.pdf> [Accessed 30 September 2021].

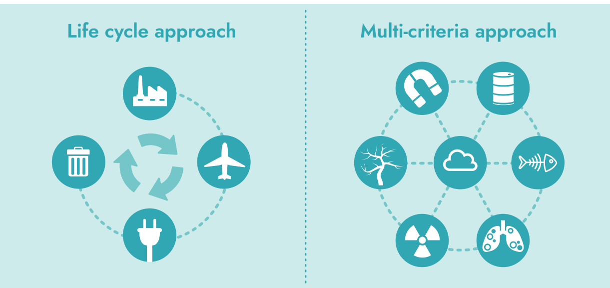
3. Methodology

3.1—LCA Methodology

3.1.1—General principles of LCA

Life cycle assessment is a method used to evaluate the environmental impact of products, services, or organisations. There are other environmental impact assessment methods, such as carbon footprint or impact assessments. But LCA has specific features that make its holistic approach unique. Indeed, used since the end of the 1990s and standardised in ISO 14040:2006[16] and ISO 14044:2006[17], this method aims to establish the environmental impact of a product or service according to several key concepts:

- **Multicriteria:** Several environmental indicators are systematically considered, including global warming potential, depletion of abiotic resources, photochemical ozone creation, water, air and soil pollution, human ecotoxicity and biodiversity. The list of indicators is not fixed but depends on the sector of activity.
- **Life cycle perspective:** To take into account the impacts generated during all stages of the life cycle of equipment or services, from the extraction of resources that are often not easily accessible to the production of waste, including installation processes, energy consumption during the use phase, etc.



- **Quantity:** Each indicator is described quantitatively to place all the external aspects of a product or a service on the same scale and to make objective decisions.
- **Function:** The object of study is defined by the function it fulfils in order to compare different technical solutions.
- **Attribution or consequence:**
    - **Attribution:** This describes the potential environmental impacts that can be attributed to a system (e.g. a product) over its life cycle, i.e. upstream along the supply chain and downstream following the system's use and end-of-life value chain. It focuses on direct effects related to a system.
    - **Consequence:** This aims to identify the consequences that a decision in the foreground system has for other processes and systems in the economy, both in the background system of the system being analysed and in other systems. It models the analysed system on these consequences. It includes indirect effects related to a system.

In the ICT sector, LCA was applied mainly in the field of products initially, but its scope has been broadened in recent years, firstly thanks to the ETSI 203 199 standard[18] and today thanks to the large body of work carried out by professional organisations in the telecommunications sector, such as the ITU, by the NegaOctet consortium for digital services or by the Ecodesign cluster for services in general.

The shift from a product to a service involves retaining the multicriteria and functional perspective but

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16 ISO. 2006. *ISO 14040:2006 - Environmental management — Life cycle assessment — Principles and framework.* [online] Available at: <https://www.iso.org/standard/37456.html> [Accessed 30 September 2021].

17 ISO. 2006. *ISO 14044:2006 - Environmental management — Life cycle assessment — Requirements and guidelines.* [online] Available at: <https://www.iso.org/standard/37456.html> [Accessed 30 September 2021].

18 2014. *Environmental Engineering (EE); Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services.* [online] ETSI. Available at: <https://www.etsi.org/deliver/etsi_es/203100_203199/203199/01.03.00_50/es_203199v010300m.pdf> [Accessed 30 September 2021].

moving from a circular approach (cradle to grave) to a matrix approach encompassing the life cycle of all the equipment making up the three entities (devices, networks, datacentre) that constitute the digital service and enable it to function.

This method of environmental diagnosis makes it possible to identify phases and avoid transfers of impacts from one to another and also from one entity to another. For example, when moving from a local solution to a SaaS solution in the cloud, the life cycle analysis will ensure that the impacts avoided at the level of user terminals will not be offset by additional impacts on the network.

3.1.2—Methodological approach of LCA

3.1.2.1—What are the different stages of an LCA?

As presented in the ISO 14040:2006 standard[19], an LCA study consists of 4 interrelated stages:

1. Goal and scope definition

2. Life cycle inventory analysis (LCI)

3. Life cycle impact assessment (LCIA)

4. Interpretation of the life cycle results

LCA is an iterative technique in which each phase uses the results of the others, contributing to the integrity and coherence of the study and its results. This is a holistic approach and so transparency of use is crucial to ensure appropriate interpretation of the results obtained.

Note: *LCA addresses potential environmental impacts and therefore does not predict actual or absolute environmental impacts.*

3.1.2.2—Goal and scope definition

The definition of the study's objective should describe the purpose of the study and the decision process for which it will provide support in environmental decision making. The purpose of an LCA should determine the intended application, the reasons for conducting the study, the intended audience, that is, the people to whom the results of the study are expected to be communicated, and whether the results are expected to be used in comparative statements that will be disclosed to the public.

The scope of an LCA - including system boundaries, level of detail, data quality, assumptions made, limitations of the study, etc. - depends on the subject and the intended use of the study. The depth and breadth of a scope can differ considerably depending on the specific objective pursued.

An LCA has a structured approach, relative to a functional and/or declared unit. All subsequent analyses are therefore related to such units. If a comparison is needed - only products or services fulfilling the same function - it is necessary to choose a functional unit in reference to the function that the products or services in question perform.

3.1.2.3—Life cycle inventory analysis

Data collection

This phase consists in the collection of data and calculation procedures to quantify the relevant inputs and outputs of the system under study. The data to be included in the inventory must be collected for each unit process considered within the boundaries of the system under study.

Elementary flow inventory

In an LCI, elementary flows should be accounted for within the system boundaries, that is, material and energy flows coming from the environment without prior transformation by human beings (e.g. consumption of oil, coal, etc.) or that enter nature directly (e.g. atmospheric emissions of CO_2, SO2, etc.) without further transformation. Elementary flows include the use of resources, air emissions and discharges to water and soil associated with the system.

The data collected, whether measured, calculated or estimated, is used to quantify all the inputs and outputs of matter and energy of the different processes.

Allocation and assignment rules

In reality, few industrial processes produce a single output: industrial processes usually produce more than one product and/or intermediate products or their waste is recycled. In this case, criteria need to be applied to

19 ISO. 2006. *ISO 14040:2006 - Environmental management — Life cycle assessment — Principles and framework.* [online] Available at: <https://www.iso.org/standard/37456.html> [Accessed 30 September 2021].

assign the environmental load to the different products, as is the case in the study carried out.

Data quality evaluation

LCA and LCI data related to digital services and equipment remains challenging. Most LCA-inspired studies use monocriterion data (such as energy or global warming), or heterogeneous datasets. In this project, we used the NegaOctet database (release due December 2021). The NegaOctet database is a 3-year long project co-financed by the French Environmental Agency (ADEME) which was still in development at the moment of the study (mid-2021). This database was undergoing a critical review by a scientific research institute at the same time of the critical review process of this same study. For this reason, the LCI database was excluded from the scope of the review of this study.

We chose this database for multiple reasons:

- It is the only homogeneous LCI database for digital equipment to date in the world, allowing the calculation of PEF EF 3.0 impact indicators
- Since we are developing the database, we have control over its design

The use of the NegaOctet database prior to its publication made it impossible to provide a complete data quality evaluation; however, the used data is the only available. Nonetheless, a summary of the data quality review is provided in the appendices to be as transparent as possible.

3.1.2.4—Life cycle impact assessment

3.1.2.4.1—Selection, classification and characterisation of the impacts

This phase aims to assess the importance of potential environmental impacts based on the results of the inventory. This process involves selecting impact categories (e.g. climate change), and assigning inventory data to these impact categories with impact category indicators (e.g. climate change in 100 years according to the CML Impact model) by means of a characterisation factor. This phase provides information for the interpretation phase.

3.1.2.4.2—Normalisation & Weighting

The numerical results of the indicators can optionally also be ordered, normalised, grouped and weighted. This approach facilitates interpretation, but no scientific consensus exists on any robust way to perform such an evaluation.

3.1.2.5—Interpretation of the life cycle results

Interpretation is the final phase of the LCA.

This includes the results of the inventory or evaluation or both, which are summarised and discussed in a comprehensible manner. This section is used by the study recipients as the basis for conclusions, recommendations and decision-making in accordance with the objective and scope established.

3.1.2.5.1—Sensitivity & Uncertainty Analysis

Some of the data is collected from the literature, which means that the model is based on secondary and therefore possibly uncertain data. In order to determine the order of magnitude of variations in results, sensitivity and uncertainty analyses have to be performed.

3.1.3—Goal and scope definition

3.1.3.1—Goal of the study

Generally speaking, carrying out a life cycle assessment of a sector of activity (here, digital activities) means relating it to its actual physical and environmental context. It is relevant to apply this method in order to:

- **Establish a quantitative diagnosis of the direct environmental impacts of digital activities at the EU-28 level**
- Identify the main contributors to the impacts
- Identify the most significant levers for improvement
- Allow a follow-up of the environmental performances in the following years
- Communicate objectively on environmental performances and possible improvement
- Feed a responsible digital strategy driven by environmental performance

This study is therefore aimed at measuring the environmental impacts of digital technologies and infrastructures in Europe in order to:

1. Shed light on the environmental impacts of digital technology to inform decision-makers

2. Bring together decision-makers and the scientific community to tackle environmental and digital transitions

3. Generalise collective awareness and empower European citizens and European strategic players

This study will therefore provide key insights and benchmarks for:

1. Recognising sensitive sectors of activity

2. Harmonising access to robust findings

3. Laying the groundwork for the development of clear digital sustainability indicators

3.1.3.2—Framework

This work tends towards compliance with ISO 14040:2006 and 14044:2006.

Wherever possible and relevant to our context, the methodological choice will also refer to complementary standards such as:

- ITU L1410 - Methodology for environmental life cycle assessments of information and communication technology goods, networks and services[20]
- PEF Guidelines[21] and PEFCR (Product Environmental Footprint Category Rules Guidance)[22] relative to IT equipment[23]

3.1.3.3—Conduct of the study

The study was organised in the following phases:

- **A scoping phase** to define the scope of the study and encompass the complexity of the system.
- **A data collection phase** covering all the equipment and usage included in our scope. This phase consisted of in-depth bibliographical research, data collection questionnaires, workshop with experts, etc.
- **A phase to develop a tailor-made tool** to calculate the environmental impacts of digitalisation at the European level using the life cycle assessment methodology.
- **The LCA**
- **Interpretation**

A presentation was made to the steering committee at the end of each phase and a review by the critical reviewers was organised to present the methodology and check the study's compliance with the ISO 14040:2006 and 14044:2006 standards and its robustness.

3.1.3.4—Intended audience

The audience targeted is mainly:

- Policy-makers
- European citizens

The study will be also useful for the wider scientific community.

The final study and final data generated are placed under a creative commons licence (CC BY-SA) to allow for broad access and use of the results for the common good.

The results are not intended to be used in comparative assertions for disclosure to the public.

3.1.3.5—Validity of results

The results are only valid for the situation defined by the assumptions described in this report. The conclusions may change if these conditions differ. The relevance and reliability of use by third parties or for purposes other than those mentioned in this report cannot therefore be guaranteed by the LCA practitioners.

It is therefore the sole responsibility of the sponsor.

3.1.4—Scope of the study

Within the framework of our study, the objective is to provide the latest knowledge (2019-2020) about the environmental impacts of digital technologies using the LCA method described above, within the scope of the European Union.

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20 Itu.int. 2014. *L.1410: Methodology for environmental life cycle assessments of information and communication technology goods, networks and services.* [online] Available at: <https://www.itu.int/rec/T-REC-L.1410/en> [Accessed 30 September 2021].

21 2017. PEFCR *Guidance document, - Guidance for the development of Product Environmental Footprint Category Rules* (PEFCRs), version 6.3. [online] European Commission. Available at: <https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf> [Accessed 30 September 2021].

22 PEFCRs (Product Environmental Footprint Category Rules Guidances), "*provide specific guidance for calculating products' life cycle potential environmental impacts. Rules analogous to PEFCRs exist in standards for other types of life cycle-based product claims, such as ISO 14025:2006 (type III environmental declarations). PEFCRs were named differently in order to prevent confusion with other analogous rules and uniquely identify rules under the PEF Guide.*" Definition from 2017. PEFCR Guidance document, - Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3. [online] European Commission. Available at: <https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf> [Accessed 30 September 2021].

23 2017. PEFCR *Guidance document, - Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs)*, version 6.3. [online] European Commission. Available at: <https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf> [Accessed 30 September 2021].

Only the direct impacts will be taken into account. Indirect impacts, positive and negative (such as direct or indirect rebound effects, substitution, structural changes), are not taken into account. This constitutes an attributional LCA.

The following paragraphs provide details of the scope of the study, i.e.:

- Functional unit
- System boundaries: inclusion, exclusion, cut-off rules
- Geographical, time and technological representativeness
- Life cycle phase considered
- Environmental impact quantified, characterisation methods
- Types and sources of the data
- Data quality requirements.

3.1.4.1—Product system to be studied

3.1.4.1.1—Technological boundaries

This study deals with digital services at the European scale. The scope of digital services covered three categories of equipment also called "tiers":

- **Tier 1 - End-user Devices:** This category includes terminals used by end users, such as computers, screens and connected objects (for connected objects, only the sensors and connected components are included, this means for example that for home appliances, that only the connected parts and sensors of connected home appliances are considered and other home appliances compontents and devices are excluded).
- **Tier 2 - Network:** This category includes network infrastructures for exchanging data between end-users' terminals and data centres. Network is composed of fixed network, mobile network and core network. It includes end-user routers.
- **Tier 3 - Data centres:** This category includes equipment related to hosting and data processing (switch, firewall, router, storage, etc.)

Illustration of a digital service defined by the 3 main categories of equipment

3.1.4.1.2—Time boundaries

This study covers all digital services in Europe in 2019. Consequently, the selected data is as representative as possible of 2019. If data is missing, it has been replaced and extrapolated as much as possible with data no older than 2015.

3.1.4.1.3—Geographical boundaries

The geographical scope considered in this study covers IT equipment located in the European Union (28 states members, including UK at the time considered (2019)).

IT equipment and infrastructures geographically located abroad are excluded.

3.1.4.2—Function and functional unit

The functional unit is the reference unit used to relate the inputs and outputs as well as the environmental performance of one or more product systems.

The function studied is the provision of digital services in the EU-28 used by consumers, private and public organisations over one year. Due to this great diversity of use, it is difficult if not impossible to categorise the use of digital services in Europe into functional units.

In such cases, the concept of functional unit is replaced by a declared unit.

"Digital service-related equipment and systems based in the European Union (28 states members) over one year".

And at the level of one EU inhabitant

"Digital service-related equipment and systems based in the European Union (28 states members) over one year related to one inhabitant".

3.1.4.3—System boundary

3.1.4.3.1—Life cycle stages considered

During this study, we considered the following life cycle phases:

1. Manufacturing stage: Includes raw material extraction, upstream transports and manufacturing processes.

2. Distribution stage: Includes the distribution between the manufacturer and the installation site.

3. Use stage: Includes at least the electricity used by IT equipment.

4. End-of-life stage: Includes the end-of-life treatment of IT equipment.

3.1.4.3.2—Inclusion

As presented previously, the study covers the digital service infrastructures and devices located throughout Europe across the three tiers.

The list of equipment covered by the study is presented below:

Tier 1 – End user devices and IoT
Smartphones
Cell phone, phone (land line via box), tablets
Laptop, desktop
Monitor / screen, monitor / screen by size, projector
TV, TV by size, TV box, game console
Printers
Connected objects (communicating part only (tag, RFID, etc.)), connected speakers
Tier 2 – Network
IT equipment involved in mobile (2G, 3G, 4G, 5G) and fixed networks (FTTX, ADSL)
Non-IT equipment involved in mobile (2G, 3G, 4G, 5G) and fixed networks (FTTX, ADSL)
Tier 3 – Data centres
IT equipment (compute, storage, network)
Non-IT equipment involved in the infrastructure (cooling systems, generators, UPS, batteries, etc.)

3.1.4.3.3—Exclusion

The following flows were excluded from the study:

- The lighting, heating, sanitation and cleaning of facilities producing the equipment, due to a lack of data
- The transportation of employees, considered outside the boundaries
- The manufacture and maintenance of production tools, due to a lack of data
- The construction and maintenance of infrastructures, due to a lack of data
- The flows from administrative, management, and R&D departments, considered outside the boundaries
- The product marketing, considered outside the boundaries
- The staff catering facilities, considered outside the boundaries
- The maintenance, reparation, remanufacturing IT activities, due to lack of data
- The impact of IT sector employees: transportation, office, lunch, etc. considered out of scope by convention (these aspects are generally accounted for in ISO 14001 site-based approaches)
- Data centres operating data consulted in Europe but located abroad, as the scope of the study only refers to equipment used on EU-28 soil
- TV/radio networks, due to the lack of information regarding the constituent equipment
- Enterprise networks, due to the lack of information regarding the constituent equipment
- PSTN (Public Switched Telephone Network), due to the lack of information regarding the constituent equipment
- Some consumer electronics like media players, cameras, GPS, due to the lack of information regarding the constituent equipment

All the above are considered outside the scope of the study.

For some of the excluded flows (TV/radio networks, PSTN, enterprise networks, consumer electronics), a sensitivity analysis was performed to include their electricity consumption.

3.1.4.3.4—Cut off rules

Generally, the environmental modelling must cover a defined percentage (greater than or equal to 95%) of the equipment or systems:

- The mass of the intermediate flows not taken into account must be less than or equal to 5% of the mass of the elements of the reference product corresponding to the functional unit,

- The energy flows not taken into account shall be less than or equal to 5% of the total primary energy used during the life cycle of the reference product corresponding to the functional unit.

However, for digital services, the verification of these cut-off rules is difficult. In the context of the study, every available piece of information was taken into consideration, considering the exclusions specified above regarding the scope of the study. The environmental assessment reveals which parts of the service under consideration have the most impact and which will be subject to a sensitivity analysis.

3.1.4.4—Allocation procedures

3.1.4.4.1—General allocations

Except for the end of life, no general allocation has been performed. Specific allocations have been performed for some devices. See Appendix Data Used in the LCA model for more details.

3.1.4.4.2—Allocation for the end of life

For the purposes of the life cycle assessment in this report, the recycling and recovery of materials at the end of their life cycle is considered using the formula developed by Ecosystem in their database[24], selecting the "without benefits" approach. This method assumes that the recycling or energy recovery of materials in the end of life does not provide any benefits related to virgin material or primary energy sources substitution.

The method, as applied with the "without benefit" approach is as follow:

- Material recycling impacts:

$$(1\text{-}A)R_2{}^*E_{recyclingEoL}$$

With:

A: allocation factor for the distribution costs and credits between the supplier and the user of recycled materials. In the Ecosystem approach, A=0.

R_2: it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system.

$E_{recyclingEoL}$: specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process.

- Impacts of energy recovery:

$$(1\text{-}B)R_3{}^*E_{ER}$$

With:

B: allocation factor for the energy recovery processes: it applies to both costs and credits. In the Ecosystem approach, B=0.

R_3: it is the proportion of the product material that is used for energy recovery at EoL.

E_{ER}: specific emissions and resources consumed (per functional unit) resulting from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, ...).

- Impacts of waste disposal:

$$(1\text{-}R_2\text{-}R_3)^*E_D$$

With:

R_2: it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system.

R_3: it is the proportion of the product material that is used for energy recovery at EoL.

E_D: specific emissions and resources consumed (per functional unit) resulting from the disposal of waste material at the EoL of the analysed product, without energy recovery.

3.1.4.5—The LCIA methodology and the types of impacts

3.1.4.5.1—Selection, classification and characterisation of the impacts

This phase aims to assess the importance of potential environmental impacts using the results of the inventory. This process involves the selection of impact categories, and the association of inventory data with impact categories (e.g. climate change) and with impact category indicators (e.g., climate change in 100 years according to the CML Impact model) through characterisation factors. This phase provides information for the interpretation phase.

In our context, we will base our analysis on the indicators proposed by the European Commission in the framework of the Product Environmental Footprint (PEF) project, using PEF 3.0. [25]

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24 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].

25 Eplca.jrc.ec.europa.eu. 2019. *European Platform on Life Cycle Assessment - Developer Environmental Footprint (EF).* [online] Available at: <https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml> [Accessed 30 September 2021].

Table 10 - The complete Set of Impact indicators recommended within the PEF methodology

Impact category	Model	Unit	LCIA method level of recommendation
Climate change	IPCC 2013, GWP 100	kg CO_2 eq	I
Ozone depletion	World Meteorological Organisation (WMO), 1999	kg CFC-11 eq	I
Particulate matter	Fantke et al., 2016	disease incidence	I
Acidification	Posch et al., 2008 ; Seppälä et al. 2006	mol H+ eq	II
Eutrophication, freshwater	Struijs et al, 2009	kg P eq	II
Eutrophication, marine	Struijs et al, 2009	kg N eq	II
Eutrophication, terrestrial	Posch et al., 2008; Seppälä et al. 2006	mol N eq	II
Ionising radiation, human health	Frischknecht et al., 2000	kBq U235 eq	II
Photochemical ozone formation, human health	Van Zelm et al., 2008, as applied in ReCiPe, 2008	kg NMVOC eq	II
Human toxicity, non-cancer	USEtox (Rosenbaum et al., 2008	CTUh	III
Land use	Soil quality index (based on Beck et al. 2010; LANCA, Bos et al., 2016)	pt	III
Resource use, fossils	ADP for energy carriers, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016)	MJ	III
Resource use, minerals and metals	ADP for mineral and metal resources, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016)	kg Sb eq	III
Water use	AWARE 100 (based on Boulay et al., 2018)	m3 world eq	III
Ecotoxicity, freshwater	USEtox (Rosenbaum et al., 2008)	CTUe	III/Interim*
Human toxicity, cancer	USEtox (Rosenbaum et al., 2008)	CTUh	III/Interim*

To make these indicators as comprehensible as possible and to focus our recommendations on the appropriate topics, it is widely accepted to reduce the complete set of indicators to an appropriate selection. In our case, the limited set of indicators is derived from the normalisation and weighting approach. We selected the most relevant indicators based on the normalised and weighted results (see Normalised and weighted results). The following indicators were selected, representing more than 80% of the global weighted results:

Table 11 - Selection of relevant indicators based on normalisation and weighting

Impact category	Model	Unit	LCIA method level of recommendation
Climate change	IPCC 2013, GWP 100	kg CO_2 eq	I
Particulate matter	Fantke et al., 2016	disease incidence	I
Acidification	Posch et al., 2008	mol H+ eq	II
Ionising radiation, human health	Frischknecht et al., 2000	kBq U235 eq	II
Photochemical ozone formation, human health	Van Zelm et al., 2008, as applied in ReCiPe, 2008	kg NMVOC eq	II
Resource use, fossils	ADP for energy carriers, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016)	MJ	III
Resource use, minerals and metals	ADP for mineral and metal resources, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016)	kg Sb eq	III
Ecotoxicity, freshwater	USEtox (Rosenbaum et al., 2008)	CTUe	III/Interim*

The indicator "water use", while representing 16,8% of weighted impacts, was removed: an issue in the accounting of water flows in ESR end of life data has been identified. After discussion with ESR, the following aspects were identified:

- The end of life processes consumes little water

- Most of the water consumption comes from the use of electricity. In this case, most of the water used should be taken from fresh water and emitted back to fresh water (corresponding to cooling water). But in the ESR data, the water is taken from fresh water and discharged into sea water. This emission is not taken into account by the water use indicator. This leads to artificially high results for the end of life. This could not be corrected within the timeframe of the study; therefore, this indicator has been removed.

The indicators "land use" was not considered relevant: many data related to mineral extraction does not take land use flows into account. This limitation is thus still present in devices data. Therefore, accounting for land use impacts would be incomplete at best and cannot be reported without a high degree of uncertainty.

In addition, we propose to complement this set with four more comprehensible indicators that are the material input per services (MIPS), waste production, primary energy and final energy. Those indicators cannot be normalised and weighted but provide an additional understanding of the environmental impacts.

Table 12 - Addition of four flow indicators

Impact category	Model	Unit	LCIA method level of recommendation
Material input per services	MIPS, Schmidt-Bleek, 1994 and Ritthoff et al., 2002	kg	N/A
Waste production (not limited to e-waste)	A compilation of 3 types of waste: 1. non-hazardous waste (inert) 2. hazardous waste (toxic, flammable, explosive, irritant, etc.) 3. radioactive The non-hasardous waste category represents the majory of the mass of waste production for ICT.	kg	N/A
Primary energy	Cumulative Energy	MJ	N/A
Final energy		MJ	N/A

In order to have a better understanding of the selected indicators, the following table details each one of them with an explanation of the related environmental aspects:

Table 13 - Description of impact & flow indicators

Impact indicators	
Abiotic resource depletion (mineral and metals) • Type of indicator: Problem-oriented impact indicator (mid-point) • Unit: kg Sb equivalent (kg Sb eq.) • Assessment method: CML 2002 • Definition: Industrial exploitation leads to a decrease in available resources that have limited reserves. This indicator assesses the amount of mineral and metal resources removed from nature as if they were antimony.	**Climate change** • Type of indicator: Problem-oriented impact indicator (mid-point) • Unit: kg CO_2 equivalent (kg CO_2 eq.) • Assessment method: IPCC 2013 method • Definition: Greenhouse gases (GHGs) are gaseous compounds that absorb infrared radiation emitted by the Earth's surface. The increase in their concentration in the Earth's atmosphere contributes to global warming.
Acidification • Type of indicator: Problem-oriented impact indicator (mid-point) • Unit: mol H+ eq. • Assessment method: Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008) • Definition: Air acidification is related to emissions of nitrogen oxides, sulphur oxides, ammonia and hydrochloric acid. These pollutants turn into acids in the presence of moisture, and their fallout can damage ecosystems as well as buildings.	**Particulate matters** • Type of indicator: Problem-oriented impact indicator (mid-point) • Unit: Disease incidence • Assessment method: PM method recommended by UNEP (UNEP 2016) • Definition: The presence of small-diameter fine particles in the air - in particular those with a diameter of less than 10 microns - represents a human health issue, as their inhalation can cause respiratory and cardiovascular problems
Ionising radiations • Type of indicator: Problem-oriented impact indicator (mid-point) • Unit: kBq U235 eq. • Evaluation method: Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000) • Definition: Radionuclides can be released during a number of human activities. When radionuclides decay, they release ionising radiation. Human exposure to ionising radiation causes DNA damage, which in turn can lead to various types of cancer and birth defects	**Photochemical ozone formation, human health** • Type of indicator: Problem-oriented impact indicator (mid-point) • Unit: kg NMVOC eq. • Assessment method: Van Zelm et al., 2008, as applied in ReCiPe, 2008 • Definition: Ground-level ozone is formed in the lower atmosphere from volatile organic compounds (VOCs) and nitrogen oxides as a result of solar radiation. Ozone is a very potent oxidant known to have health effects because it easily penetrates the respiratory tract
Abiotic resource depletion (fossil) • Type of indicator: Problem-oriented impact indicator (mid-point) • Unit: MJ • Assessment method: CML 2002 Definition: The indicator represents primary energy consumption from different non-renewable sources (oil, natural gas, etc.). The calculations are based on the Lower Heating Value (LHV) of the energy types considered, expressed in MJ/kg. For example, 1 kg of oil will contribute 41.87 MJ to the indicator considered.	**Ecotoxicity, freshwater** • Type of indicator: Problem-oriented impact indicator (mid-point) • Unit: CTUe • Assessment method: USEtox (Rosenbaum et al., 2008) Definition: These indicators track the entire impact chain from the emission of a chemical component to the final impact on humans and ecosystems. This includes modeling environmental distribution and fate, exposure of human populations and ecosystems, and toxicity-related effects associated with exposure.
Flow indicators	
Mass of waste generated • Type of indicator: Flow indicator • Unit: kg • Definition: Quantity of wastes generated along the life cycle, including WEEE (Waste Electrical and Electronic Equipment), as well as wastes generated related to the extraction of raw materials which will virtually have to be reprocessed	**Primary energy consumption** • Type of indicator: Flow indicator • Unit: MJ • Definition: Primary energy is the first form of energy directly available in nature before any transformation: wood, coal, natural gas, oil, wind, solar radiation, hydraulic or geothermal energy, etc.
Final energy consumption • Type of indicator: Flow indicator • Unit: MJ Definition: Refers to the energy directly used by the end-user, in the form of electricity or fuel	**Raw materials** • Type of indicator: Resource consumption indicator • Unit: kg • Evaluation method: MIPS - Material Input per Service-unit • Definition: The MIPS indicator calculates the resources used to produce a unit of product or service using a life cycle analysis approach (Schmidt-Bleek, 1994). Five types of resources are considered: abiotic resources (materials, fossil energy, etc.), biomass, mechanical or erosive land movement, water, and air (Ritthoff et al., 2002). These consumptions are simply summed up, which gives an indicator of resource consumption (extracted raw materials and energy raw materials)

3.1.4.5.2—Normalisation & Weighting

The numerical results of the indicators can optionally also be ordered, normalised, grouped, and weighted. This approach facilitates the interpretation, but no scientific consensus exists on a robust way to perform such an evaluation.

In our study, we used the normalisation and weighting factors provided by the JRC in the PEF/OEF method (EF 3.0), released on 20 November 2019, such as reported in the table below.

Table 14 - Normalisation factors proposed by the JRC

Impact category	Normalisation factor	Unit
Climate change	8.10E+03	kg CO_2 eq./person
Ozone depletion	5.36E-02	kg CFC-11 eq./person
Particulate matter	5.95E-04	disease incidences/person
Acidification	5.56E+01	mol H+ eq./person
Eutrophication, freshwater	1.61E+00	kg P eq./person
Eutrophication, marine	1.95E+01	kg N eq./person
Eutrophication, terrestrial	1.77E+02	mol N eq./person
Ionising radiation, human health	4.22E+03	kBq U-235 eq./person
Photochemical ozone formation, human health	4.06E+01	kg NMVOC eq./person
Human toxicity, non-cancer	2.30E-04	CTUh/person
Land use	8.19E+05	pt/person
Resource use, fossils	6.50E+04	MJ/person
Resource use, minerals and metals	6.36E-02	kg Sb eq./person
Water use	1.15E+04	m3 water eq of deprived water/person
Ecotoxicity, freshwater	4.27E+04	CTUe/person
Human toxicity, cancer	1.69E-05	CTUh/person

Table 15 - Weighting factors proposed by the JRC

Impact category	Weighting factor (%)
Climate change	21.06
Ozone depletion	6.31
Particulate matter	8.96
Acidification	6.20
Eutrophication, freshwater	2.80
Eutrophication, marine	2.96
Eutrophication, terrestrial	3.71
Ionising radiation, human health	5.01
Photochemical ozone formation, human health	4.78
Human toxicity, non-cancer	1.84
Land use	7.94
Resource use, fossils	8.32
Resource use, minerals and metals	7.55
Water use	8.51
Ecotoxicity, freshwater	2.8
Human toxicity, cancer	2.13

3.1.4.6—Type and source of data

An LCA calculation requires two different kinds of information:

- Data related to the **physical characteristics** of the considered system (such the number of smartphones used in Europe and the amount of electricity consumed by the smartphones). For this project, these data come from a statistic and internal benchmark.

- Data related to the **life cycle impacts** of IT equipment or energy flows that enter the considered system. These data come from the databases available in EIME software thanks to the NegaOctet project.

Data related to the physical characteristics

The diversity of the resources covered enabled both a broad and accurate coverage of the environmental impacts of digital technologies and infrastructures, covering one of these 10 sectors: ICT (transversal), ICT (equipment), WEEE, digital practices, components, media/entertainment, EEE, ICT (data centres), ICT (networks), IoT.

Our bibliographic resources, collected and updated throughout the data collection phase of our study, allowed us to gather an up to date 2019-2020 inventory describing environmental impacts of the digital services in Europe.

These bibliographic resources were the ground of our work for carrying out the LCA and the case studies.

Data related to the life cycle impacts

Data on the life cycle impacts of IT equipment or energy flows are classified into the following categories:

Primary data (also referred to as "site-specific data") – data gathered from the actual manufacturing plant where the product-specific processes are carried out, and data from other parts of the life cycle traced back to the specific product system under study, e.g. materials or electricity provided by a contracted supplier that is able to provide data for the actual delivered services, transportation that takes place based on actual fuel consumption, and related emissions, etc.

Secondary data divided into:

- **selected secondary data –** data from commonly available data sources that fulfil prescribed data quality characteristics of accuracy, completeness, and representativeness,

- **proxy data –** data from commonly available data sources (that do not fulfil all of the data quality characteristics of "selected secondary data").

In accordance with the objectives and limitations of the system, no specific data has been privileged. Most of the data were taken from the databases available in EIME software (selected secondary data): NegaOctet[26] and CODDE[27] databases.

3.1.4.7—Data quality requirements

In accordance with the objectives and limitations of the system, the required quality of the data collected follows the rules described below:

- **Technological representativeness:** representative of technologies between 2015 and 2020.

- **Geographical representativeness:** specific data corresponding to the digital services related equipment located in European Union (28 Member States) during its use, considering that some of their life cycle phases such as manufacturing may occur abroad (market-based approach). If data are missing, assumptions are justified when possible.

- **Time-related representativeness:** data from 2019-2020. When data are older than 5 years (before 2015), they were updated with assumptions and justified when possible.

- **Completeness:** the application of cut-off criteria is complex considering the amount of equipment and processes. The study includes all identified flows, unless stated otherwise.

- **Parameter uncertainty:** for most of the data, only one source was available, resulting in a high degree of uncertainty. Where possible, data were cross-checked with additional sources.

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26 NegaOctet https://negaoctet.org/
27 LCIE Department CODDE Bureau Veritas https://codde.fr/en/our-services/software-tools

- **Methodological appropriateness and consistency:** methodology used: ISO 14040-44. Consistent application of the data collection methodology for all components under study.

3.1.4.8—LCA Modelling tool

For each device, the flow of material and energy resources from the environment into the technical system and the emissions from the technical system to air, soil, and water are taken into account by the EIME version 5.9.1. software and its database. EIME is compliant with the ILCD Handbook (entry level-I).

The assessment of the overall European digital services for 1 year has been performed by compiling all the equipment data in an Excel tool.

3.1.4.9—Critical review considerations

The critical review is a procedure for certifying that the Life Cycle Assessment (LCA) complies with international standards and national supplements to meet the study's objectives. It is carried out mainly when the results are intended to be communicated to the public or when it concerns comparative claims. Its purpose is to limit the risks in terms of:

- Inconsistency between the objective, data collection and results of the study
- Communication of unsubstantiated conclusions

In our context, the critical review also aims to:

- Identify the important elements and limitations of the study to establish that it is not distorted, and its communication is not biased.
- Ensure the relevance and reliability of the information given.

The critical review of the study conducted for the Greens/EFA to validate the assumptions, data and procedures used to conduct the study, is carried out by:

- **Ana Belen MORAL BALANDIN,** Sustainability consultant at Quantis
- **Sebastien HUMBERT,** Co-founder, Scientific Director and Sustainability consultant at Quantis,

The critical review was carried out on an ongoing basis and was conducted in several stages:

- Review 1 of the study scope and main assumptions – April 2021
- Review 2 of the life cycle inventory and assumptions – July 2021
- Review 3 of results, interpretation, and final report – August/September 2021

This review included:

- the methodology,
- the preliminary report,
- the life cycle analysis,
- results and sensitivity analysis,
- the final report.

The critical review report is available on request from the authors at *info@greenit.fr.*

3.1.5—Treatment of missing data

3.1.5.1—Generic approach

In case of missing data or difficulties in choosing between certain data sources (once the relevance of the source has been assessed), the chosen methodological approach is to attribute the worst-case scenario – penalising the data. Indeed, due to the iterative nature of the life cycle analysis, such an approach makes it possible to identify whether the data is sensitive or not and, if necessary, to carry out an uncertainty analysis.

3.1.5.2—Lifespan

Currently, there is no harmonised definition of the concept of lifespan[28]. This notion is understood and interpreted differently considering the actors involved (manufacturers, users, end-of-life treatment operators). 4 different concepts can therefore be proposed:

- **Normative lifetime:** the average operating lifetime measured under specific test conditions, defined in standards established by organization such as AFNOR, CENELEC or IEC, for example, or, failing that, by non-standardised tests whose methodology is explicit, transparent and recognised.

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28 2012. *Étude Sur La Durée De Vie Des Équipements Électriques Et Électroniques - Rapport Final.* [online] ADEME. Available at: *<https://librairie.ademe.fr/dechets-economie-circulaire/3516-etude-sur-la-duree-de-vie-des-equipements-electriques-et-electroniques.html>* [Accessed 30 September 2021].

- **Useful life span:** the period during which the product is used, i.e., in working order and ready for use, by a given user. It is user/household specific. The total useful life is the sum of the useful lives.

- **Ownership life span:** the time between the date of entry into the household (not necessarily new) and the date of exit from the household (in working order or not). This includes storage time. It is user/household specific. It includes possible repairs. The total holding period is the sum of the holding periods. It corresponds to the time between the purchase of a new appliance and its transition to waste status, regardless of the condition of the appliance (in working order or not). It includes possible repair and re-use. The total duration of ownership is thus greater than or equal to the total duration of use, due to the possible storage of appliances in households.

- **Existence life span:** the period between the end of manufacture of the product and its disposal, recovery, or recycling. It differs from the total ownership period in that it includes the possible re-use of a product after it has become waste, as well as the time between the end of manufacture and the new purchase.

Thus, ideally, equipment should be characterized according to its useful lifetime. However, the lack of transparency of the sources, as to the methodology used to define the lifespan, does not allow us to identify said lifetime with precision for every equipment. Indeed, it is extremely complex to know the proportion and duration of second lives of equipment.

3.1.5.3—E-waste

Data related to effective End-of-Life of devices is extremely difficult to find, if not impossible due to the lack of tracking of e-waste.

Although some projects such as the Urban Mine Platform[29] have exist and have been funded by the European Union in order to more accurately depict the actual e-waste flows, these projects are limited both in time and by high uncertainties. Indeed, these projects suffer a lot from the lack of harmonised data between Member States and only depicts a small share of the actual flows, at a given time – the Urban Mine Platform project does not give more recent data than 2015 for e-waste flows.

We also looked very carefully into the Global E-Waste Monitor 2020 report, which is interesting as it offers a global overview of the e-waste issues, although it cannot bring answers to the specific flows of e-waste per device in the EU.

As no data were found regarding e-waste collection and recycling rates per device in the EU, the only end of life scenario that is sufficiently precise to be modelled at our level of knowledge is a theoretical scenario in which the EU WEEE Directive is fully respected by all Members States.

On this basis, we have considered all waste as if it were treated in regulated pathways. While this leads to a probable underestimation of end-of-life impacts, the only possible alternative would have been not to consider all flows exiting the regulated pathways.

Some information is also described by the Ecosystem database used in this report: "*data produced and released are intended to represent the end-of-life management of the material/WEEE stream pairs studied within the framework of the French WEEE take-back scheme, not ruling out that some operations downstream from the depollution and rank 1 treatment operations are carried out in other European countries or in Asia. This involves representing an average national management for France. The data produced are not however intended to represent a specific local geographical context such as the management of the WEEE collected in a given department (e.g.: Loire), in a given community (e.g., Mâcon), in the overseas departments and territories, etc. A local context is likely to differ significantly from the national average management.*"

Considering that e-waste is an increasing and complex issue regarding the environmental impacts of ICT, and to give a more practical and global overview of the subject, we conducted a case study on **e-waste & circular economy**.

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29 Urbanmineplatform.eu. 2015. *Jaco Huisman, Pascal Leroy, François Tertre, Maria Ljunggren Söderman, Perrine Chancerel, Daniel Cassard, Amund N. Løvik, Patrick Wäger, Duncan Kushnir, Vera Susanne Rotter, Paul Mählitz, Lucía Herreras, Johanna Emmerich, Anders Hallberg, Hina Habib, Michelle Wagner, Sarah Downes. Prospecting Secondary Raw Materials in the Urban Mine and mining wastes (ProSUM) - Final Report, ISBN: 978-92-808-9060-0 (print), 978-92-808-9061-7 (electronic), December 21, 2017, Brussels, Belgium.* [online] Available at: <http://www.urbanmineplatform.eu/homepage> [Accessed 30 September 2021].

4. LCA Study findings

In tables including percentages, the total may not always equal to 100% due to rounding.

The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

4.1—Global evaluation

4.1.1—Global evaluation for 1 year of digital services in Europe

4.1.1.1—Total results

Global results for the environmental impacts of 1 year of digital services in Europe, EU-28 are presented in the following table:

Table 16 - Overall impacts of EU-28 digital services impacts (environmental impacts & flow indicators)

Resource use, minerals and metals - tonnes Sb eq.	5,760
Resource use, fossils- PJ	3,960
Acidification - mol H+ eq. (in billions)	1.19
Ecotoxicity, freshwater - CTUe	3,090
Climate change - Mt CO_2 eq.	185
Ionising radiation, human health - GBq U235 eq.	278
Particulate matter - Disease occurrence	8,000
Photochemical ozone formation - human health - tonnes NMVOC eq.	464,000
Raw materials - Mt	571
Waste production - Mt	116
Primary energy consumption - PJ	4,230
Final energy consumption (use) - PJ	1,020

Specifically, climate change is 185 Mt CO_2 eq.

In order to provide some element of comparison with common values, some impacts can be expressed through understandable equivalents:

Resource use, mineral and metals is equivalent to 111t of gold in terms of rarity, and 571 Mt of displaced materials, equivalent to the weight of 9.2 billion humans (averaging 62 kg). This means that each year, the displaced materials related to EU-28 digital services roughly equal the weight of all human beings.

Climate change impacts are similar to 370,000 round trips of a 500-passenger-equivalent plane between Paris and New York, or about 63 years of the actual connection (16 planes per day)

Waste production is equal to the weight of 1.87 billion humans (averaging 62 kg)

Electricity consumption is equal to 32,344,000 heaters (1,000 W) powered non-stop for a year.

In addition, at an EU-28 scale:

Total electricity consumption for digital services in Europe is 283 TWh out of a total of 3,054 TWh[30], which means that electricity consumption for digital services during the use phase accounts for 9.3% of European electricity consumption.

Total GHG emissions for digital services in Europe are 185 Mt CO_2 eq. out of a total of 4,378 Mt CO_2 eq.[31], which means that GHG emissions from digital services account for 4.2% of the European GHG emissions.

30 IEA. 2021. *Data & Statistics - IEA*. [online] Available at: <https://www.iea.org/data-and-statistics/data-browser?country=EU28&fuel=Electricity%20and%20heat&indicator=TotElecCons> [Accessed 30 September 2021].

31 EEA. 2021. *Data viewer on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU Member States)*. [online] Available at: <https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer> [Accessed 30 September 2021].

Note

The EU-28 scale comparisons are aimed at providing a scale of related impacts and must not be understood as absolute results.

The perimeters are different: some emissions related to digital services in the EU-28 occur outside EU-28 and are considered within the scope of the study (manufacturing of the devices); while the total emissions considered for the EU by the IEA are only emissions occurring within EU borders.

To learn more about imported emissions: *https://www.idhsustainabletrade.com/news/hidden-CO2-emissions-europes-imported-responsibility/*

4.1.2—Normalised and weighted results

In order to determine the relative importance of each impact in relation to the others, the normalisation and weighting methods have been performed, based on EF 3.0 method.

Only the impact indicators can be assessed. The other indicators (raw materials, waste production, primary energy consumption and final energy consumption) are not displayed.

4.1.2.1—Normalisation

The first step is the normalisation, aiming to quantify each impact in terms of world population equivalent. E.g., a value of 50 for the climate change indicator means that the climate change impact is equal to the annual emissions of 50 average world inhabitants.

The normalised results provide an understanding of the scale of the impacts of digital services for each impact category. The higher the number, the more digital services in Europe contribute to the global issue related to each category.

The normalised results are as follow:

Table 17 - Normalised results

World inhabitants	
Resource use, minerals and metals	90,586,462
Resource use, fossils	60,890,581
Acidification	21,502,337
Ecotoxicity, freshwater	72,343,598
Climate change	22,884,595
Ionising radiation, human health	65,819,104
Particulate matter	13,442,000
Photochemical ozone formation - human health	11,440,400

4.1.2.2—Weighting

Finally, the normalised results are weighted, which means that their relative importance is determined based on a methodology developed by the JRC[32], based on public and expert surveys as well as evidence-based expert opinions[33]. For this part, all impact indicators have been assessed, as the weighted results are used to distinguish significant from negligible impacts (see chapter *Selection, classification and characterisation of the impacts*. The results are as follow:

Table 18 - Weighted results

	TIER 1 End user devices	TIER 2 Network	TIER 3 Data centres	Total	Total excluding toxicity related impact categories
Resource use, minerals and metals	20.4%	1.4%	1.2%	22.9%	24.2%
Resource use, fossils	10.5%	2.4%	4.1%	17.0%	17.9%
Acidification	2.9%	0.5%	1.0%	4.5%	4.7%
Ecotoxicity, freshwater	3.2%	0.5%	1.0%	4.7%	N/A
Human toxicity, cancer	0.2%	0.0%	0.0%	0.2%	N/A
Human toxicity, non-cancer	0.3%	0.0%	0.1%	0.5%	N/A
Eutrophication, freshwater	0.0%	0.0%	0.0%	0.0%	0.0%
Eutrophication marine	0.6%	0.1%	0.2%	0.8%	0.9%
Eutrophication, terrestrial	0.8%	0.2%	0.3%	1.3%	1.3%
Climate change	10.6%	1.9%	3.6%	16.2%	17.1%
Ionising radiation, human health	7.2%	1.6%	2.2%	11.1%	11.7%
Ozone depletion	0.1%	0.0%	0.0%	0.1%	0.1%
Particulate matter	2.6%	0.5%	0.9%	4.0%	4.3%
Photochemical ozone formation - human health	1.2%	0.2%	0.4%	1.8%	1.9%

32 Joint Research Center https://ec.europa.eu/jrc/en
33 For more details, see 2018. *Development of a weighting approach for the Environmental Footprint.* [online] JRC. Available at: <https://ec.europa.eu/environment/eussd/smgp/documents/2018_JRC_Weighting_EF.pdf> [Accessed 30 September 2021].

In compliance with PEFCR guidance v.6.3[34]: "*The most relevant impact categories shall be identified as all impact categories that cumulatively contribute to at least 80% of the total environmental impact (excluding toxicity related impact categories). This should start from the largest to the smallest contributions.*"

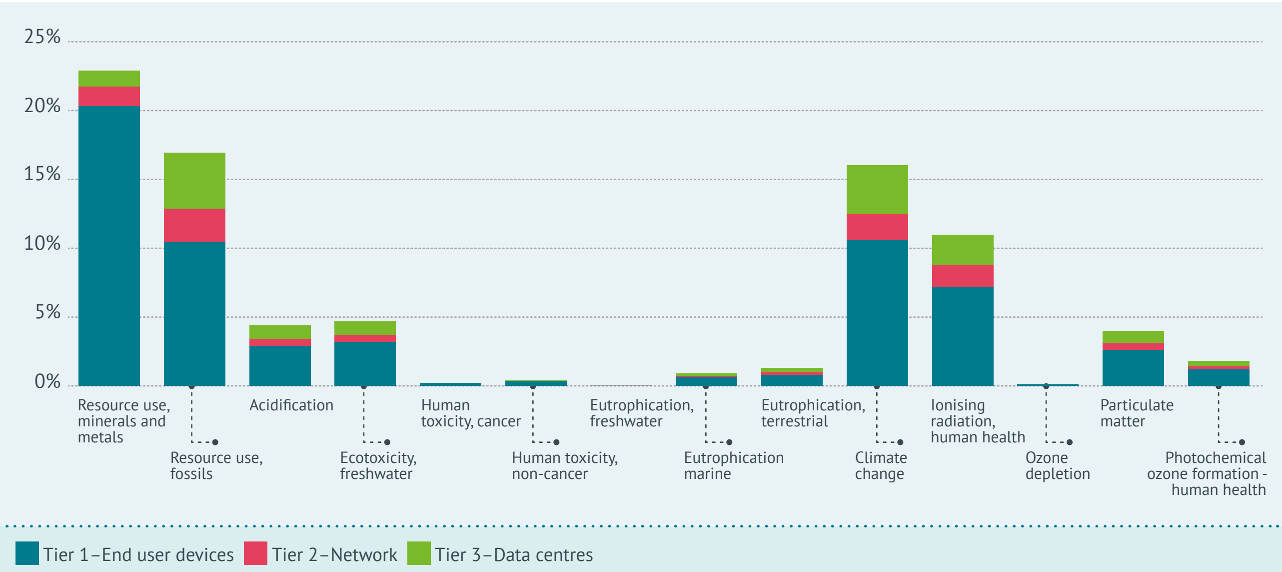
The most important impacts accounting for 80% are, in order:

- Resource use, minerals and metals.
- Resource use, fossils.
- Climate change.
- Ionising radiation, human health.
- Acidification.
- Particulate matter.
- Photochemical ozone formation - human health.

The indicator "Ecotoxicity, freshwater" has been added back despite the uncertainty related to it in order to provide insight into an important environmental issue related to digital services. Indeed, the electronic equipment requires resources that have significant toxic impacts on the environment and human life. For example, extraction of lithium for batteries, or the illegal waste treatment. While this indicator still has a high level of uncertainty, this issue should be addressed more precisely in future updates.

The other indicators are thus considered negligible and do not represent a significant environmental aspect for digital services.

Figure 1 - Normalised and weighted impact distribution along the 3 tiers



34 2017. PEFCR Guidance document, - *Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs)*, version 6.3. [online] European Commission. Available at: <https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf> [Accessed 30 September 2021].

4.1.3—Planetary boundaries

Impacts can be compared to planetary boundaries, to provide additional insight into the relative importance of each indicator.

Planetary boundaries is a concept that enables to compare environmental impacts to the planetary limits, which is a framework helping to estimate in what extend the human activities respect or exceed the safe operating space for humanity.

The planetary boundaries are not a fully integrated method in LCA approaches, and some discussions at scientific level are still ongoing. Nonetheless, the Joint Research Centre has provided factors linking LCA results and planetary boundaries[35]. Those factors are used in this chapter and adapted to consider the budget at EU-28 level (ratio using the number of inhabitant).

Table 19 - Planetary boundaries results

	EU-28 boundaries per indicator	Percentage of EU-28 boundaries per indicator
Resource use, minerals and metals - kg Sb eq.	14,700,000	39.3%
Resource use, fossils - MJ	15,000,000,000,000	26.4%
Acidification - kg mol H+ eq.	66,900,000,000	1.8%
Ecotoxicity, freshwater - CTUe	8,770,000,000,000	35.2%
Human toxicity, cancer - CTUh	64,400	0.1%
Human toxicity, non-cancer - CTUh	274,000	0.6%
Eutrophication, freshwater - kg P eq.	389,000,000	0.2%
Eutrophication marine - kg N eq.	13,500,000,000	1.2%
Eutrophication, terrestrial - mol N eq.	410,000,000,000	0.4%
Climate change - kg CO_2 eq.	456,000,000,000	40.7%
Ionising radiation, human health - kBq U235 eq.	35,300,000,000,000	0.8%
Ozone depletion - kg CFC-11 eq.	36,100,000	0.1%
Particulate matter - disease occurrence	34,500	23.2%
Photochemical ozone formation, human health - kg NMVOC eq.	27,200,000,000	1.7%

The results are to be understood as, for example: impacts on climate change caused by the EU-28 digital services are equivalent to 40.7% of the EU-28 budget of planetary boundaries.

The impact categories presenting the highest percentage use of the planetary boundaries budget use are, in order:

- Climate change
- Resource use, minerals and metals,
- Ecotoxicity, freshwater
- Resource use, fossils
- Particulate matters

With the exception to the higher importance of ecotoxicity, the relevant indicators are close to the normalisation and weighting approach.

4.1.4—Average environmental impact for 1 European

This chapters aims to give an overview of the overall environmental impacts related to one European inhabitant.

The total EU-28 population has been defined considering an EU-28 population of 513,500,000 persons in 2019[36].

The impacts for one European inhabitant are thus:

Table 20 - Digital services impacts per EU-28 inhabitant (environmental impacts & flow indicators)

Resource use, minerals and metals - g Sb eq.	11.2
Resource use, fossils- MJ	7,710
Acidification - mol H+ eq.	2
Ecotoxicity, freshwater - CTUe	6,010
Climate change - kg CO_2 eq.	361
Ionising radiation, human health - kBq U235 eq.	541
Particulate matter - Disease occurrence	0.00156%
Photochemical ozone formation - human health - kg NMVOC eq.	0.91
Raw materials - kg	1,110
Waste production - kg	225
Primary energy consumption - MJ	8,230
Final energy consumption (use) - MJ	1,980

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35 2019. *Consumption and Consumer Footprint: methodology and results - Indicators and assessment of the environmental impact of European consumption.* [online] JRC. Available at: <https://op.europa.eu/en/publication-detail/-/publication/fa4e68e9-1b69-11ea-8c1f-01aa75ed71a1/language-en> [Accessed 30 September 2021].
36 2019. Eurostat news release. *EU population up to over 513 million on 1 January 2019.* [online] Available at: <https://ec.europa.eu/eurostat/documents/2995521/9967985/3-10072019-BP-EN.pdf/e152399b-cb9e-4a42-a155-c5de6dfe25d1> [Accessed 30 September 2021].

Specifically, climate change is 361 kg CO_2 eq.

In order to provide some element of comparison to common values, some impacts can be expressed as understandable equivalents:

- Climate change impacts are similar to 1 round trip by a plane passenger between Paris and Athens.
- Resource use, mineral and metals: 0.69 kg of tin in terms or rarity, and 1,110 kg of displaced materials, equivalent to the weight of 18 humans (averaging 62 kg).
- Waste production: 225 kg of global waste, equivalent to the weight of 3.6 humans (averaging 62 kg).
- Electricity consumption: 1 heater (1,000 W) powered non-stop for 23 days.

4.1.4.1—Breakdown of impacts by digital services areas

This chapter aims to provide a first level of impact distribution, along the three tiers – end user devices, network and data centres.

Table 21 - Impact distribution along the 3 tiers

	Tier 1 End user devices	Tier 2 Network	Tier 3 Data centres
Resource use, minerals and metals	88.8%	5.9%	5.3%
Resource use, fossils	62.0%	14.1%	23.9%
Acidification	65.8%	12.1%	22.1%
Ecotoxicity, freshwater	69.4%	10.1%	20.5%
Climate change	65.5%	11.9%	22.5%
Ionising radiation, human health	65.5%	14.4%	20.2%
Particulate matter	64.0%	13.0%	22.9%
Photochemical ozone formation - human health	67.3%	11.4%	21.3%
Raw materials	66.7%	12.2%	21.2%
Waste production	78.6%	8.6%	12.8%
Primary energy consumption	58.2%	15.6%	26.2%
Final energy consumption (use)	53.8%	17.9%	28.2%

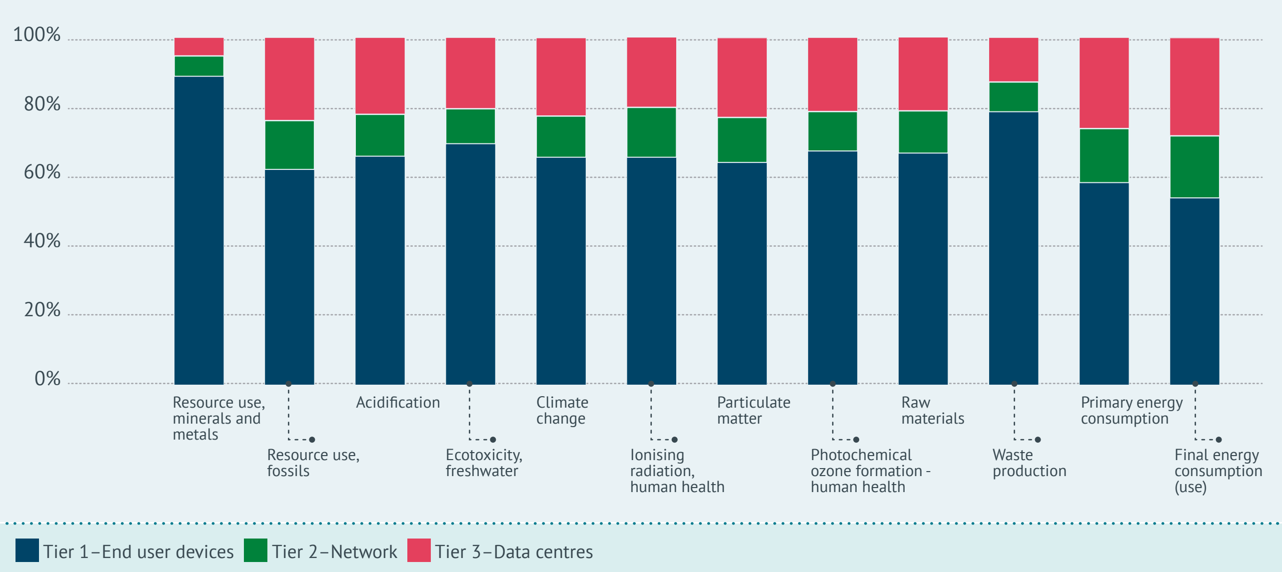
It shows that the end user devices are responsible for most of the impacts for every indicator (from 58% to 89%), followed by the data centres (from 5% to 29%) and the network (from 6% to 18%).

The tier 1 equipment on one hand, and tier 2 and 3 equipment on the other have different usage profiles:

- Tier 1 equipment has a low intensity of use, most of the time devices are in standby or switched off. This leads to an impact profile with a greater emphasis on the manufacturing phase, and the related impacts (use of resources, mineral and metals, waste production).
- Tier 2 and 3 devices have a more intensive use. Most of them are used all the time, or for a large portion of their lifespan. This leads to an impact profile with a greater emphasis on the use phase, and the related impacts.

Overall, the tier 1 contains the largest number of devices, and even though they are not as used as tier 2 and 3 devices, they account for most of the impacts. This is also increased by the important effort performed by manufacturers and operators to optimise networks and datacentres on one side, compared to the multiplication of devices on the consumer side.

Figure 2 – Impact distribution along the 3 tiers



4.1.4.2—Breakdown by life cycle stage

This chapter aims to provide a second level of impact distribution, along the three tiers – end user devices, network, and data centres – and the life cycle phases – Manufacturing, distribution, use and end of life.

Table 22 - Impact distribution along life cycle phases

	Resource use, minerals and metals	Resource use, fossils	Acidification	Ecotoxicity, freshwater	Climate change	Ionising radiation, human health	Particulate matter	Photochemical ozone formation - human health	Raw materials	Waste production	Primary energy consump-tion	Final energy consump-tion (use)
TIER 1 - Manufacturing	88.6%	23.2%	31.7%	30.7%	32.8%	33.5%	27.4%	34.0%	41.7%	69.0%	15.0%	0.0%
TIER 1 - Distribution	0.0%	0.6%	1.8%	0.0%	1.0%	0.0%	1.5%	3.8%	0.1%	0.1%	0.6%	0.0%
TIER 1 - Use	0.1%	37.6%	31.0%	24.8%	31.0%	32.0%	34.3%	28.6%	24.2%	9.5%	42.2%	53.8%
TIER 1 - End of life	0.1%	0.5%	1.3%	13.9%	0.8%	0.0%	0.9%	1.0%	0.7%	0.1%	0.5%	0.0%
TIER 2 - Manufacturing	5.9%	1.5%	1.6%	1.2%	1.5%	3.7%	1.5%	1.7%	4.1%	5.3%	1.5%	0.0%
TIER 2 - Distribution	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%
TIER 2 - Use	0.0%	12.5%	10.3%	8.3%	10.3%	10.7%	11.4%	9.5%	8.1%	3.2%	14.1%	17.9%
TIER 2 - End of life	0.0%	0.0%	0.1%	0.6%	0.1%	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
TIER 3 - Manufacturing	5.3%	4.0%	5.6%	6.3%	5.9%	3.4%	4.7%	5.7%	8.3%	7.8%	4.1%	0.0%
TIER 3 - Distribution	0.0%	0.1%	0.1%	0.0%	0.2%	0.0%	0.2%	0.5%	0.0%	0.0%	0.1%	0.0%
TIER 3 - Use	0.0%	19.8%	16.3%	13.0%	16.4%	16.8%	18.0%	15.0%	12.7%	5.0%	22.1%	28.2%
TIER 3 - End of life	0.0%	0.0%	0.1%	1.1%	0.1%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
TOTAL - Manufacturing	99.8%	28.7%	38.9%	38.3%	40.1%	40.5%	33.5%	41.3%	54.1%	82.1%	20.5%	0.0%
TOTAL - Distribution	0.0%	0.8%	2.0%	0.0%	1.2%	0.0%	1.8%	4.4%	0.2%	0.1%	0.7%	0.0%
TOTAL - Use	0.1%	69.9%	57.6%	46.0%	57.8%	59.4%	63.7%	53.1%	44.9%	17.7%	78.4%	100.0%
TOTAL - End of life	0.1%	0.6%	1.5%	15.7%	0.9%	0.1%	1.0%	1.1%	0.9%	0.2%	0.6%	0.0%

The manufacturing and use phases appear to be the most relevant phases for all three tiers. The impacts of manufacturing account for the majority of the resource use, minerals and metals, and the raw material impacts. Both impacts are related to the extraction of raw materials, which occurs mainly during the manufacturing phase. The use phase is the most impactful phase for all other impacts, as the electricity consumption of ICT-related devices is significant, and the EU-28 electricity mix is still heavily fossil-based (36% of production).

Regarding manufacturing, the equipment-related impacts are important for two main reasons:

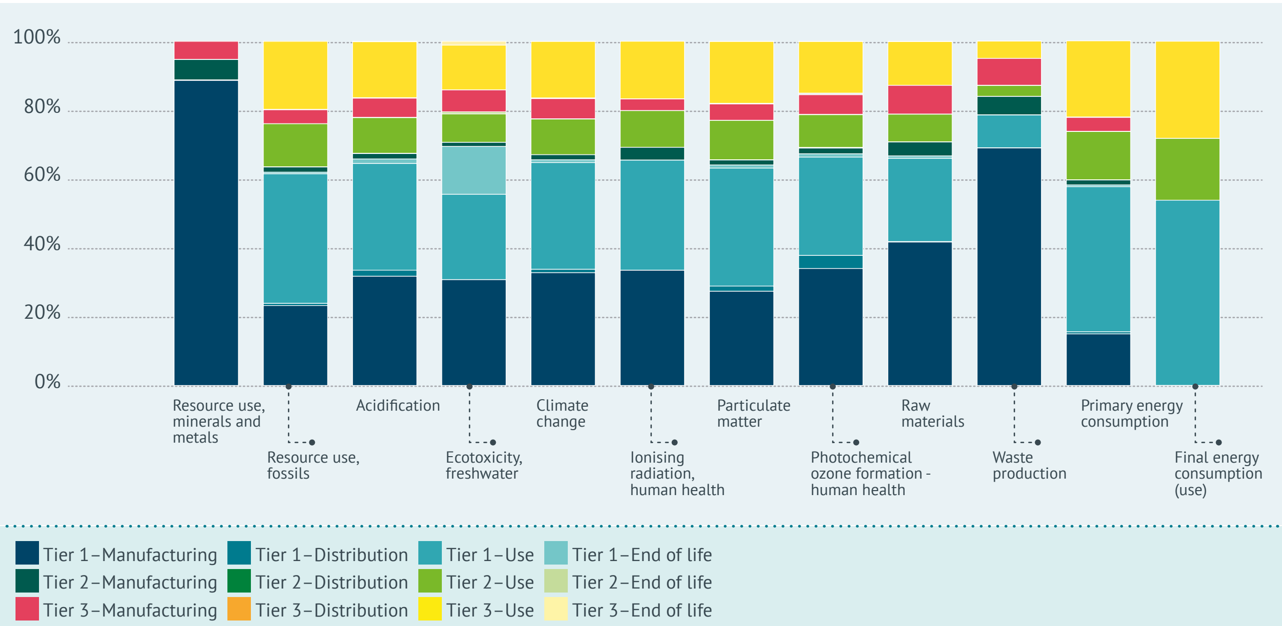
- ICT equipment, more specifically the integrated circuits, are very energy intensive. This energy is mainly produced in countries with a high fossil-based electricity mix (Asia). It leads to high impacts on most indicators.
- ICT equipment uses a large quantity and variety of rare materials (gold, silver, copper, rare earths, etc.). These materials also require significant resources and energy consumptions and generates a lot of waste (mainly extracted mineral wastes). It explains the high impacts on resources use and waste production.

The distribution and end of life have a lesser, but noy negligible impact (from 0% to 16% all tiers combined). The highest impact comes from the ecotoxicity, related to the end-of-life processes, releasing polluting substances into nature.

It can be noted that when plane transportation occurs (smartphones, tablets), the distribution impacts are higher.

It can also be noted that the impacts of waste production seem negligible for the end of life. This is due to the fact that a greater amount of waste is produced during manufacturing and use (e.g. a 3.7 kg computer generates 225 kg of wastes during manufacturing, and 53 kg during use) than end of life (where a large part is recycled). This is also explained by the assumption made when modelling the end of life, which is, as a reminder, based on a 100% compliance with the EU WEEE Directive by all Member States, which means that the end of life modelled in this study considers all waste flows exiting through the regulated[37] pathways.

Figure 3 - Impact distribution along life cycle phases



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37 Eur-lex.europa.eu. 2020. *EU waste management law.* [online] Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=LEGISSUM:ev0010&from=FR> [Accessed 30 September 2021].

4.2—Specific focus on each digital service area

The following chapters aim to provide in-depth details on the cause of the impacts related to digital services in Europe. Each tier – end user equipment, network, and data centres – is assessed individually.

4.2.1—TIER 1 - End-user equipment

4.2.1.1—Contribution analysis

The end user equipment represents a large variety of devices, with different environmental impacts and quantities. This chapter details the results to show which devices are responsible for most of the impacts.

Table 23 - Detailed impact distribution – End user devices focus

	Resource use, minerals and metals	Resource use, fossils	Acidification	Ecotoxicity, freshwater	Climate change	Ionising radiation, human health	Particulate matter	Photochemical ozone formation - human health	Raw materials	Waste production	Primary energy consumption	Final energy consumption (use)
Laptops	14.3%	6.5%	8.5%	10.2%	8.7%	4.7%	7.6%	9.0%	3.5%	4.2%	3.7%	3.0%
Tablets	4.0%	2.5%	3.3%	3.6%	3.4%	1.2%	2.9%	3.9%	3.5%	7.9%	2.5%	1.1%
Smartphones	9.7%	5.8%	8.3%	9.0%	9.0%	1.4%	7.1%	9.6%	1.3%	1.9%	1.2%	0.7%
Feature phones	1.0%	0.1%	0.2%	0.2%	0.2%	0.0%	0.2%	0.2%	0.3%	1.0%	0.1%	0.0%
Desktops	10.0%	6.1%	6.3%	8.50 %	6.1%	9.5%	6.1%	6.2%	9.7%	10.7%	6.4%	4.6%
Monitors	1.8%	1.2%	1.1%	1.0%	1.1%	1.3%	1.2%	1.1%	1.0%	1.0%	1.2%	1.3%
TVs	19.8%	13.2%	11.9%	10.3%	11.7%	13.3%	12.4%	11.8%	14.9%	21.5%	14.3%	14.3%
Projectors	0.2%	0.4%	0.3%	0.3%	0.3%	0.6%	0.4%	0.3%	0.3%	0.2%	0.4%	0.5%
TV box	7.3%	4.7%	4.6%	4.5%	4.5%	8.5%	4.7%	4.3%	6.6%	7.1%	5.1%	5.4%
Landline phones	0.8%	1.6%	1.5%	1.3%	1.4%	1.7%	1.6%	1.4%	1.9%	1.4%	1.8%	2.0%
Desktop game consoles	6.6%	2.1%	2.4%	2.8%	2.3%	5.7%	2.3%	2.3%	3.9%	5.4%	2.2%	1.8%
Mobile game consoles	0.5%	0.4%	0.5%	0.6%	0.6%	0.5%	0.4%	0.5%	0.6%	0.6%	0.4%	0.1%
Connected speakers	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.4%	0.4%	0.3%	0.3%
External HDD	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.0%	0.0%
External SSD	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%
USB keys & Micro SD	0.3%	0.3%	0.5%	0.5%	0.6%	0.1%	0.4%	0.5%	0.6%	0.4%	0.3%	0.0%
Printers	3.8%	4.5%	4.5%	5.5%	4.1%	4.0%	4.6%	4.7%	4.9%	4.4%	4.7%	4.1%
Other screens	4.7%	4.1%	3.6%	3.0%	3.6%	4.0%	3.9%	3.5%	4.1%	5.3%	4.5%	4.8%
Docking stations	1.7%	0.1%	0.2%	0.4%	0.2%	0.2%	0.2%	0.2%	0.7%	0.6%	0.1%	0.0%
IoT	1.6%	8.1%	7.5%	7.4%	7.4%	8.3%	7.9%	7.3%	8.2%	4.5%	8.9%	9.8%

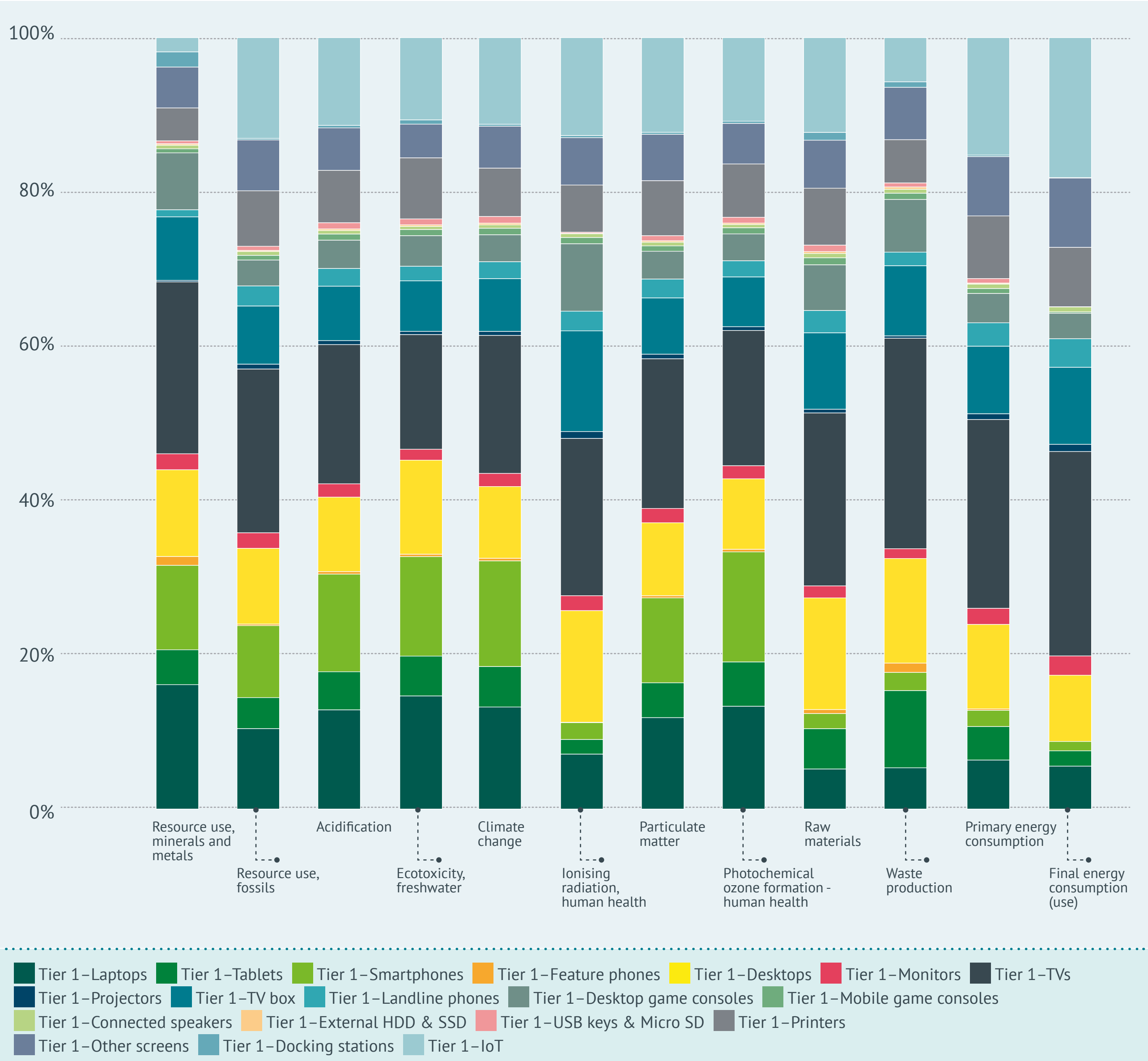
Along all indicators, it shows that while there is not a single or a few types of devices responsible for most impacts, it is possible to select a short list of devices causing the most impacts:

- TVs
- Laptops
- Tablets
- Smartphones
- Desktops
- TV boxes
- Desktop game consoles
- Printers
- Other screens
- IoT

Other devices are causing fewer impact, either because of their small number and/or their low individual impacts.

Overall, the multiplication of devices at consumer levels, personal or companies, is responsible for a large part of the impacts. Actions such as the mutualisation of equipment, the prolongation of their lifespan and the reduction of their individual environmental impact is an important lever for reducing impacts.

Figure 4 - Detailed impact distribution – End user devices focus



4.2.1.2—Focus on manufacturing, distribution and end of life of user equipment

The manufacturing, distribution, and end of life of equipment are the impacts related to the acquisition and discard choices of the user (as opposed to the use phase which is related to the behaviour of the user during use). It is thus interesting to separate them.

Table 24 – Detailed impact distribution – End user devices focus – Manufacturing, distribution and end of life phases

	Resource use, minerals and metals	Resource use, fossils	Acidification	Ecotoxicity, freshwater	Climate change	Ionising radiation, human health	Particulate matter	Photochemical ozone formation - human health	Raw materials	Waste production	Primary energy consumption	Final energy consumption (use)
Laptops	16.1%	17.9%	19.3%	19.7%	20.1%	8.6%	19.1%	19.0%	5.0%	5.3%	8.4%	0.0%
Tablets	4.5%	7.2%	7.6%	6.9%	8.2%	1.8%	7.4%	8.5%	7.1%	11.1%	10.5%	0.0%
Smartphones	10.9%	21.9%	22.8%	19.4%	24.9%	3.1%	22.3%	23.9%	2.4%	2.5%	4.5%	0.0%
Feature phones	1.1%	0.5%	0.6%	0.5%	0.6%	0.1%	0.6%	0.6%	0.8%	1.4%	0.7%	0.0%
Desktops	11.2%	11.7%	10.6%	14.2%	10.0%	20.1%	10.5%	9.6%	17.8%	14.2%	17.1%	0.0%
Monitors	2.1%	1.3%	1.1%	0.8%	1.0%	1.4%	1.1%	1.1%	1.0%	1.1%	1.0%	0.0%
TVs	22.3%	13.1%	10.5%	8.4%	10.2%	14.5%	11.2%	10.9%	20.1%	27.4%	19.2%	0.0%
Projectors	0.2%	0.2%	0.2%	0.1%	0.1%	0.9%	0.2%	0.2%	0.2%	0.2%	0.2%	0.0%
TV box	8.2%	3.8%	4.4%	4.6%	4.0%	16.0%	4.2%	3.8%	9.9%	9.0%	5.5%	0.0%
Landline phones	0.9%	0.9%	1.0%	0.9%	0.8%	1.4%	1.0%	0.9%	2.4%	1.5%	1.3%	0.0%
Desktop game consoles	7.4%	3.4%	4.0%	4.3%	3.7%	13.9%	4.0%	3.6%	7.4%	7.3%	5.1%	0.0%
Mobile game consoles	0.5%	1.3%	1.3%	1.1%	1.4%	1.4%	1.3%	1.2%	1.3%	0.9%	1.9%	0.0%
Connected speakers	0.5%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.5%	0.5%	0.4%	0.0%
External HDD	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.3%	0.1%	0.0%
External SSD	0.0%	0.3%	0.3%	0.2%	0.3%	0.0%	0.3%	0.3%	0.2%	0.1%	0.4%	0.0%
USB keys & Micro SD	0.4%	1.4%	1.5%	1.2%	1.6%	0.3%	1.4%	1.3%	1.3%	0.6%	2.0%	0.0%
Printers	4.3%	6.4%	6.0%	8.0%	5.0%	4.6%	6.5%	6.3%	7.2%	5.3%	9.3%	0.0%
Other screens	5.3%	2.9%	2.4%	1.8%	2.2%	3.4%	2.6%	2.5%	4.6%	6.5%	4.2%	0.0%
Docking stations	2.0%	0.4%	0.6%	0.8%	0.4%	0.5%	0.5%	0.5%	1.6%	0.8%	0.6%	0.0%
IoT	1.8%	5.2%	5.4%	6.5%	5.0%	7.5%	5.5%	5.4%	9.0%	4.0%	7.5%	0.0%

The results are similar to the observations made in chapter 4.2.1.1., but the importance of TVs is reduced compared to other devices. This is due to the high energy consumption of TV compared to other devices, as well as the importance of electronic components in IT devices, mainly processors, RAM and SSD due to the silicon wafer.

Around 70% of impacts are caused by five types of equipment:

- Laptops
- Tablets
- Smartphones
- Desktops
- TVs

Another aspect is that LCD displays lead to higher electricity consumption in use phase, so devices with a large LCD display (TVs, monitors, other screens) have a lower relative impact when the use phase is not included.

The impact of "Final energy consumption" (use) is null, as it only concerns the electricity consumption in the use phase.

4.2.1.3—Focus on the use phase of the user equipment

The use phase only consists of the electricity consumption, as the potential upgrades and repairs (e.g. replacement of smartphones display panel, addition of new or replacement of desktop components, etc.) are not taken into account.

The distribution of the impact across all impact indicators is thus the same.

Table 25 - Detailed impact distribution – End user devices focus – Use phase

	Resource use, minerals and metals	Resource use, fossils	Acidification	Ecotoxicity, freshwater	Climate change	Ionising radiation, human health	Particulate matter	Photochemical ozone formation - human health	Raw materials	Waste production	Primary energy consumption	Final energy consumption (use)	Total energy consumption per year (TWh)
Laptops	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	8.46
Tablets	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	3.03
Smartphones	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.85
Feature phones	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.004
Desktops	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	13.1
Monitors	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	3.81
TVs	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	40.4
Projectors	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	1.42
TV box	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	15.2
Landline phones	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	5.65
Desktop game consoles	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	5.03
Mobile game consoles	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.266
Connected speakers	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.982
External HDD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0095
External SSD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0007
USB keys & Micro SD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.021
Printers	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	11.7
Other screens	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%	13.7
Docking stations	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0698
IoT	18.2%	18.2%	18.2%	18.2%	18.2%	18.2%	18.2%	18.2%	18.2%	18.2%	18.2%	18.2%	27.7

The results are a direct picture of the electricity consumption for each device. This consumption for each category is indicated in the last column, for information.

TVs have the highest energy consumption. They have a large number of units as well as high individual consumption.

The second most important cause of impacts is the IoT. Although individual devices have lower impacts, they constitute the category with the most devices, especially regarding commercial building controls (624,589,079 units estimated) and smart meters (223,067,528 units estimated). Indeed, commercial building controls and smart meters represents altogether more than 56% of the IoT devices and more than 12.1 TWh over the 27.7 TWh consumed by the IoT devices.

For these 2 types of devices (commercial building controls and smart meters seem to be mainly supplied continuously by the electrical network), the hypothesis considered by the IEA accounts for a standby mode which does not spend less energy than an active mode. This configuration and the associated results departs from the conception that connected objects would majorly consume very little electricity in standby mode to preserve their battery. Although we are talking here of a consumption of 1.5 to 2 W per device (based on IEA hypothesis), the already large number of devices weighs significantly in the impacts.

It must be noted that portable devices (smartphones, tablets, laptops...) have a lower power consumption. The customer demand for increased autonomy is directly encouraging manufacturers to work on electricity consumption. This can be observed by comparing the portable and stationary versions of a device, such as:

- Laptop (30.96 kWh/year) versus desktop (104.39 kWh/year)
- Portable console (5.15 kWh/year) versus desktop console (55.88 kWh/year)
- Feature phone (0.09 kWh/year) versus landline phone (17.57 kWh/year)

Note: *values only for illustration, usage and performance vary.*

4.2.2—TIER 2 - Networks

4.2.2.1—Contribution analysis

Networks can be divided into fixed-line (xDSL, FTTx), and mobile (2G, 3G, 4G, 5G). While the separation between the two networks is not complete, as some devices are shared[38], this chapter presents the impact of both network types separately (see Table 26 below).

Fixed-line network has a higher environmental impact than mobile network. It requires a larger quantity of equipment (mainly home routers, access copper cables and optical fibres) as well as higher energy consumption.

Nonetheless, it must be noted that the amount of transferred data and subscribers is also not the same. Impacts can be reported to:

- The amount of transferred GB for each network:
  - 64 EB (Exabyte = 10^9 Gigabyte) for the mobile network.
  - 518 EB for the fixed-line network.
- The number of subscribers to each network:
  - 623,540,000 for the mobile network.
  - 195,969,905 subscribers for the fixed-line network.

> **Note**
>
> These numbers are not a scale, they only represent an average of everything that happens in a whole network over time. **These figures cannot be used in any way to understand the environmental impact related to one GB per say.** Network impacts are not necessarily proportional to the number of subscribers or transferred GB. Results shown below only present an allocation of these impacts to better apprehend the scale of those caused by networks.

For results, see Table 27 (below).

Table 26 - Detailed impact distribution – Network focus

	Resource use, minerals and metals	Resource use, fossils	Acidification	Ecotoxicity, freshwater	Climate change	Ionising radiation, human health	Particulate matter	Photochemical ozone formation - human health	Raw materials	Waste production	Primary energy consumption	Final energy consumption (use)
Fixed-line network	84.1%	71.8%	72.2%	73.0%	72.2%	74.3%	71.9%	72.6%	75.1%	79.5%	71.6%	70.1%
Mobile network	15.9%	28.2%	27.8%	27.0%	27.8%	25.7%	28.1%	27.4%	24.9%	20.5%	28.4%	29.9%

Table 27 - Comparison of impacts per GB & per surbscriber

		Resource use, minerals and metals - mg Sb eq.	Resource use, fossils - MJ	Acidification - mol H+ eq.	Eco-toxicity, freshwater -CTUe	Climate change - kg CO_2 eq.	Ionising radiation, human health - kBq U235 eq.	Particulate matter - Disease occurrence per 1 bilion	Photo-chemical ozone formation - human health - mg NMVOC eq.	Raw materials - kg	Waste production - kg	Primary energy consumption - MJ	Final energy consumption (use) - MJ
Per GB of transferred data	Fixed-line network	0.557	0.773	0.000202	0.439	0.0307	0.0572	1.45	74.5	0.101	0.0153	0.909	0.248
	Mobile network	0.851	2.460	0.000629	1.320	0.096	0.16	4.57	227	0.271	0.0318	2.910	0.853
Per subscriber	Fixed-line network	1,470	2,040	0.533	1,160	81.20	151	3,820	197,000	266	40.4	2,400	654
	Mobile network	87.3	252	0.0645	135	9.85	16.4	469	23,300	27.8	3.27	299	87.6

38 Separation hypotheses are presented in appendix Data Used in the LCA model —Manufacturing, distribution and end of life

4.2.2.2—Focus on mobile network

Mobile network's impacts are distributed between three main layers:

- Access layer: links the end-user's devices to the network
- Aggregation, or distribution layer: links the access layer to the backbone layer
- Backbone, or core layer: allows a large quantity of data to be transferred at high speed on long distances

In this assessment, only the manufacturing, distribution and end of life phases are taken into account. Collected data for the electricity consumption in use phase could not be differentiated between access, aggregation or backbone.

For results, see Table 28 (below).

The access layer is responsible for a majority of the impacts, due to the base station number and individual impact. As antennas cover most of the territory, the number of base stations is important. The aggregation and backbone are mutualised, with highly efficient devices.

4.2.2.3—Focus on the fixed-line network

The fixed-line network impacts can be distributed along three main layers:

- Access layer: links the end-user devices to the network
- Aggregation, or distribution layer: links the access layer to the backbone layer
- Backbone, or core layer: allows a large quantity of data to be transferred at high speed on long distances

In this assessment, only the manufacturing, distribution and end of life phases are taken into account. The collected data for the electricity consumption in use phase could not be differentiated between access, aggregation or backbone.

For results, see Table 29 (below).

The access layer is responsible for a majority of impacts, due to the number of modems available. As each subscriber has a modem installed in their building, this feature is important. The aggregation and backbone are mutualised, with highly efficient devices.

Table 28 - Mobile network impacts distribution – without use phase

	Resource use, minerals and metals	Resource use, fossils	Acidification	Ecotoxicity, freshwater	Climate change	Ionising radiation, human health	Particulate matter	Photochemical ozone formation - human health	Raw materials	Waste production	Primary energy consumption
Access	83.5%	80.8%	89.2%	87.2%	86.9%	83.0%	86.0%	88.8%	88.4%	81.8%	80.1%
Aggregation	9.6%	15.5%	6.6%	7.6%	8.1%	13.4%	10.1%	7.2%	6.9%	10.7%	16.3%
Backbone	6.9%	3.6%	4.2%	5.2%	4.9%	3.6%	3.8%	4.0%	4.7%	7.5%	3.6%

Table 29 - Fixed-line network impacts distribution – without use phase

	Resource use, minerals and metals	Resource use, fossils	Acidification	Ecotoxicity, freshwater	Climate change	Ionising radiation, human health	Particulate matter	Photochemical ozone formation - human health	Raw materials	Waste production	Primary energy consumption
Access	76.3%	65.8%	81.1%	81.3%	78.8%	73.5%	74.5%	81.3%	83.2%	74.9%	65.0%
Aggregation	13.2%	28.7%	11.9%	10.9%	13.6%	21.4%	19.3%	12.4%	9.6%	14.3%	29.7%
Backbone	10.5%	5.5%	7.0%	7.8%	7.6%	5.1%	6.2%	6.3%	7.2%	10.9%	5.4%

4.2.3—TIER 3 - Data centres

4.2.3.1—Contribution analysis – Per type of data centres

Data centres are divided into several types: cloud, traditional and edge. Each type requires a different number of data centres with specific characteristics. For results, see Table 30 (below).

By order of importance, the most impacting data centres are traditional ones, followed by cloud and, edge ones.

Traditional data centres are still the most common ones to be found in EU-28, despite the growth of cloud data centres. They have the largest surface, number of servers and energy consumption.

Demand for cloud data centres is growing as cloud-based solutions are more and more used by companies and individuals. Nonetheless, they are generally more efficient than traditional data centre (lower PUE).

Finally, edge data centres only represented a fringe of the impact in 2019, but the development of the 5G network should lead to an increase in number.

4.2.3.2—Contribution analysis – Per type of equipment and consumption

Data centres are made of different kinds of equipment:

- Computing: servers providing computing power
- Storage: both SSD and HDD used to store data
- Network: switches and routers used to direct data
- Architectural and technical support equipment

They also imply kinds of energy consumption:

- For computing and storage
- For technical support equipment
- Refrigerant leaks coming from cooling systems.

For results, see Table 31 (below).

Table 30 - Detailed impact distribution – Data centres focus per type of data centres

	Resource use, minerals and metals	Resource use, fossils	Acidification	Ecotoxicity, freshwater	Climate change	Ionising radiation, human health	Particulate matter	Photochemical ozone formation - human health	Raw materials	Waste production	Primary energy consumption	Final energy consumption (use)
Cloud	38.3%	37.3%	37.3%	37.3%	37.3%	37.3%	37.3%	37.3%	37.4%	37.8%	37.3%	37.2%
Traditional	58.9%	59.9%	59.9%	59.9%	59.9%	59.9%	59.9%	59.9%	59.8%	59.4%	59.9%	60.0%
Edge	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%

Table 31 - Detailed impact distribution for data centres - focus per type of equipment and consumption

	Resource use, minerals and metals	Resource use, fossils	Acidification	Ecotoxicity, freshwater	Climate change	Ionising radiation, human health	Particulate matter	Photochemical ozone formation - human health	Raw materials	Waste production	Primary energy consumption	Final energy consumption (use)
Computing equipment	67.0%	12.8%	20.0%	25.1%	20.8%	9.4%	15.8%	20.8%	24.8%	34.1%	11.4%	0.0%
Storage equipment	12.8%	2.1%	3.4%	3.8%	3.6%	0.5%	2.8%	3.5%	4.0%	7.5%	1.9%	0.0%
Network equipment	2.8%	0.2%	0.2%	0.2%	0.2%	0.1%	0.1%	0.2%	0.4%	1.0%	0.1%	0.0%
Architecture and technical support equipment	16.7%	2.4%	3.0%	7.5%	2.5%	6.8%	2.8%	4.9%	10.9%	18.3%	2.1%	0.0%
Computing, storage and network energy consumption	0.4%	47.7%	42.5%	36.7%	41.7%	48.1%	45.3%	40.8%	34.6%	22.6%	48.8%	57.8%
Technical support equipment energy consumption	0.3%	34.8%	31.0%	26.8%	30.5%	35.1%	33.1%	29.8%	25.3%	16.5%	35.6%	42.2%
Refrigerant leaks	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

In general, the energy consumption represents most the impacts on most of the indicators.

As the PUE (Power Usage Effectiveness) has decreased over the years, thanks to more energy-efficient datacentres, the impacts related to energy-consumption for technical support equipment is reducing.

Secondly, computing and storage equipment are responsible for most of the impacts due to their large number and individual impact. ICT equipment requires a lot of energy and materials during manufacturing.

In third place comes the architecture and technical equipment supporting the IT equipment. While representing the vast majority of the volume in a datacentre, they have much less individual impact as they are a much simpler type of equipment. Their lifespan is also greater than for IT equipment.

In fourth place comes network equipment. While the number of devices is important, network equipment has a lower individual impact than servers or storage equipment in a data centre.

Other elements are negligible.

5. Sensitivity analyses

5.1—Global

5.1.1—Sensitivity analysis on excluded devices and networks

As stated in the Exclusion section, for some exclusions (TV/radio networks, PSTN, enterprise networks, consumer electronics), a sensitivity analysis is run to include their electricity consumption.

Associated electricity consumptions are as follow:

Table 32 – Sensitivity analysis – Excluded devices and networks – Input data

Exclusion	Electricity consumption (TWh)
Satellite & terrestrial TV	1.8 [i]
PSTN (Public Switched Telephone Network)	6.5 [ii]
Enterprise networks	5 [ii]
DVD players	0.7[iii]
Interactive whiteboard	0.25 [iv]
MP3 players	0.05 [v]
Stand-alone home audio equipment	11.6 [vi]
ATM	0.17 [vii]
Cash registers and POS terminals	2.35 [vii]
Ticket machines	0.04 [vii]
Public WLAN hotspots	4.79 [vii]
Toll-related ICT	0.03 [vii]
Security cameras	6.53 [vii]
Total	**48.01**

[i] 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.VII. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

[ii] Malmodin, J., & Lundén, D. 2018. The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015. Sustainability, 10(9), 3027. doi:10.3390/su10093027

[iii] 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.85. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

[iv] *Ibid*, p.95

[v] *Ibid*, p.98

[vi] *Ibid*, p.101

[vii] *Ibid*, p.153

In addition, the impacts from the manufacturing, distribution and end of life have been extrapolated, considering the average impact of all three phases, related to the consumption of 1 TWh.

Note

This approach, while allowing for a more comprehensive accounting, introduces a large degree of uncertainty. Indeed, impacts of manufacturing, distribution and use for some devices or networks do not necessarily translate to other devices or networks. For example, impacts of satellite network manufacturing have a different profile than that of ICT as a whole.

The calculation of manufacturing, distribution and end of life impacts related to 1 TWh are measured from total impacts.

For global impacts, see Table 33 (below).

For 1 TWh consumption, see Table 34 (below).

For results, see Table 35 (below).

Table 33 - Overall impacts of EU-28 digital services impacts (environmental impacts & flow indicators)

Resource use, minerals and metals - tonnes Sb eq.	5,760
Resource use, fossils- PJ	3,960
Acidification - mol H+ eq. (in billions)	1.19
Ecotoxicity, freshwater - CTUe	3,090
Climate change - Mt CO_2 eq.	185
Ionising radiation, human health - GBq U235 eq.	278
Particulate matter - Disease occurrence	8,000
Photochemical ozone formation - human health - tonnes NMVOC eq.	464,000
Raw materials - Mt	571
Waste production - Mt	116
Primary energy consumption - PJ	4,230
Final energy consumption (use) - PJ	1,020

Table 34 - Overall impacts – Ratio to 1 TWh

Resource use, minerals and metals - kg Sb eq.	20,300
Resource use, fossils- MJ	4,200,000,000
Acidification - mol H+ eq.	1,790,000
Ecotoxicity, freshwater - CTUe	5,890,000,000
Climate change - kg CO_2 eq.	276,000,000
Ionising radiation, human health - kBq U235 eq.	398,000,000
Particulate matter - Disease occurrence	10
Photochemical ozone formation - human health - kg NMVOC eq.	770,000
Raw materials - kg	1,110,000,000
Waste production - kg	336,000,000
Primary energy consumption - MJ	3,230,000,000
Final energy consumption (use) - MJ	0.00

Table 35 - Sensitivity analysis – Excluded devices and networks – Results

	Base case	Additional impacts - Manufacturing, distribution, end of life	Additional impacts - Use
Resource use, minerals and metals	100.0%	16.9%	0.0%
Resource use, fossils	100.0%	5.1%	13.0%
Acidification	100.0%	7.2%	10.6%
Ecotoxicity, freshwater	100.0%	9.2%	8.8%
Climate change	100.0%	7.2%	11.9%
Ionising radiation, human health	100.0%	6.9%	0.1%
Particulate matter	100.0%	6.2%	9.0%
Photochemical ozone formation - human health	100.0%	8.0%	9.9%
Raw materials	100.0%	9.3%	8.4%
Waste production	100.0%	13.9%	3.7%
Primary energy consumption	100.0%	3.7%	14.3%
Final energy consumption (use)	100.0%	0.0%	17.0%

Taking into account excluded devices and network adds a total of 7% to 19% to the impacts. Exacts impacts would have to be more precisely assessed, as some devices or networks could have a much higher or lower impact than anticipated. For example, the satellite network has impacts associated to both the conception and launching.

Specifically, for climate change, total impacts are as follow:

Table 36 - Sensitivity analysis – Excluded devices and networks – Focus on climate change

	Base case	Additional impacts - Manufacturing, distribution, end of life	Additional impacts - Use
Total climate change for EU28 (Mt CO_2 eq.)	185	13	22
Climate change for one EU28 inhabitant (kg CO_2 eq.)	361	25.8	43

5.2—Sensitivity analysis on equipment

5.2.1—Sensitivity analysis on number of equipment

The number of each piece of equipment varies depending on selected sources. For example, the number of smartphones varies from 452,745,000 to about 500,000,000. This sensitivity analysis presents the results modification occurring from the lowest to the highest range of values.

The source used are described in the appendix Data used in the LCA model. When no other source was found, a -/+ 20% was applied by default.

Table 37 – Sensitivity analysis – Number of devices – Input data

Users devices	Base number	Minimum number	Maximum number	Comment
Laptops	273,333,333	232,311,000	328,000,000	+ 20% was applied by default for the maximum value
Tablets	156,091,954	135,863,000	187,310,345	+ 20% was applied by default for the maximum value
Smartphones	473,567,151	470,678,600	500,000,000	
Feature phones	41,179,752	32,942,802	44,068,346	- 20% was applied by default for the minimum value
Desktops	125,266,207	99,227,000	150,319,448	+ 20% was applied by default for the maximum value
Monitors	54,397,952	43,518,362	93,861,325	- 20% was applied by default for the minimum value
TV	225,514,952	180,411,962	493,700,000	- 20% was applied by default for the minimum value
Projectors	7,084,138	5,403,000	8,500,966	+ 20% was applied by default for the maximum value
TV boxes	208,328,200	133,000,000	249,993,840	+ 20% was applied by default for the maximum value
Landline phones	321,382,299	285,937,000	385,658,759	+ 20% was applied by default for the maximum value
Desktop consoles	90,010,347	72,008,278	108,012,416	No other sources, a +- 20% was applied by default
Portable consoles	51,730,218	41,384,174	62,076,262	No other sources, a +- 20% was applied by default
Connected speakers	42,691,700	28,700,000	51,230,040	+ 20% was applied by default for the maximum value
External HDD	32,515,000	26,012,000	39,018,000	No other sources, a +- 20% was applied by default
External SSD	7,031,100	5,624,880	8,437,320	No other sources, a +- 20% was applied by default
USB keys	586,740,000	469,392,000	704,088,000	No other sources, a +- 20% was applied by default
Printers	127,667,700	102,134,160	130,304,000	- 20% was applied by default for the minimum value
Other screens	32,616,349	26,093,079	50,506,275	- 20% was applied by default for the minimum value
Docking stations	6,930,050	5,544,040	8,316,060	No other sources, a +- 20% was applied by default
IoT	1,873,767,237	1,499,013,790	2,248,520,684	No other sources, a +- 20% was applied by default

Results are as follow:

Table 38 - Sensitivity analysis – Number of devices – Results

	Base case	Min.	Max.
Resource use, minerals and metals	100.0%	89.3%	112.8%
Resource use, fossils	100.0%	89.1%	112.3%
Acidification	100.0%	89.2%	112.2%
Ecotoxicity, freshwater	100.0%	88.9%	112.2%
Climate change	100.0%	89.4%	112.1%
Ionising radiation, human health	100.0%	87.9%	112.5%
Particulate matter	100.0%	89.1%	112.2%
Photochemical ozone formation - human health	100.0%	89.4%	112.1%
Raw materials	100.0%	88.6%	112.0%
Waste production	100.0%	89.1%	112.1%
Primary energy consumption	100.0%	88.7%	112.3%
Final energy consumption (use)	100.0%	88.3%	112.8%

Modifying the number of devices changes results on a range going from 88% to 113% overall. The number of end-user devices is a key factor in the impact of digital services in the EU-28.

Specifically, for climate change, total impacts are as follow:

Table 39 – Sensitivity analysis – Number of devices – Focus on climate change

	Base impacts	Min.	Max.
Total climate change for EU28 (Mt CO_2 eq.)	185	166	208
Climate change for one EU28 inhabitant (kg CO_2 eq.)	361	323	404

5.2.2—Sensitivity analysis on equipment lifespan

The lifespan of each piece of equipment varies depending on selected sources. For example, the lifespan of laptops varies from 4 to 5 years. This sensitivity analysis presents the value variation from the lowest to the highest range of values.

The source used are described in the appendix Data used in the LCA model. When no other source was found, a -/+ 20% was applied by default.

Table 40 – Sensitivity analysis – Equipment lifespan – Input data

Users devices	Base lifespan (years)	Minimum lifespan (years)	Maximum lifespan (years)	Comment
Laptops	4	3.2	5	- 20% was applied by default for the minimum value
Tablets	3	2.4	4.6	- 20% was applied by default for the minimum value
Smartphones	2.5	2	3	+ 20% was applied by default for the maximum value
Feature phones	2.5	2	3	+ 20% was applied by default for the maximum value
Desktops	5.5	4.4	6	- 20% was applied by default for the minimum value
Monitors	6	4.8	7.2	No other sources, a +- 20% was applied by default
TV	8	6	9.6	+ 20% was applied by default for the maximum value
Projectors	5	4	6	No other sources, a +- 20% was applied by default
TV boxes	5	4	6	No other sources, a +- 20% was applied by default
Landline phones	8	7	10	
Desktop consoles	6.5	5.2	7.8	No other sources, a +- 20% was applied by default
Portable consoles	6.5	5.2	7.8	No other sources, a +- 20% was applied by default
Connected speakers	5	4	6	No other sources, a +- 20% was applied by default
External HDD	5	4	6	No other sources, a +- 20% was applied by default
External SSD	5	4	6	No other sources, a +- 20% was applied by default
USB keys	5	4	6	No other sources, a +- 20% was applied by default
Printers	5	4	6	- 20% was applied by default for the minimum value
Other screens	6	4.8	7	- 20% was applied by default for the minimum value
Docking stations	5	4	6	No other sources, a +- 20% was applied by default
IoT	Depends on the device see Appendix Data Used in the LCA model > IoT connected objects	Depends on the device see Appendix Data Used in the LCA model > IoT connected objects	Depends on the device see Appendix Data Used in the LCA model > IoT connected objects	No other sources, a +- 20% was applied by default

Results are as follow:

Table 41 – Sensitivity analysis – Equipment lifespan – Results

	Base case	Max.	Min.
Resource use, minerals and metals	100.0%	123.7%	84.9%
Resource use, fossils	100.0%	103.8%	93.2%
Acidification	100.0%	106.9%	91.7%
Ecotoxicity, freshwater	100.0%	109.8%	90.6%
Climate change	100.0%	106.8%	91.7%
Ionising radiation, human health	100.0%	106.6%	92.6%
Particulate matter	100.0%	105.4%	92.4%
Photochemical ozone formation - human health	100.0%	108.1%	91.1%
Raw materials	100.0%	109.6%	91.3%
Waste production	100.0%	118.1%	87.2%
Primary energy consumption	100.0%	101.4%	94.4%
Final energy consumption (use)	100.0%	96.4%	96.4%

Modifying the equipment lifespan changes results on a range from 85% to 124% overall. The lifespan of end-user devices is a key factor in the impact of digital services in the EU-28. The longer the lifespan of an equipment, the more the impacts are distributed over time, and therefore are reduced.

Specifically, for climate change, total impacts are as follow:

Table 42 - Sensitivity analysis - Equipment lifespan - Focus on climate change

	Base impacts	Max.	Min.
Total climate change for EU28 (Mt CO_2 eq.)	185	198	170
Climate change for one EU28 inhabitant (kg CO_2 eq.)	361	385	331

5.2.3—Sensitivity analysis on energy consumption of equipment

The energy consumption of each piece of equipment varies depending on selected sources. For example, tablets' power consumption varies from 10 kWh/year to 18.6 kWh/year. This sensitivity analysis presents the value variation from the lowest to the highest range of values.

The source used are described in the appendix Data used in the LCA model. When no other source was found, a -/+ 20% was applied by default.

Table 43 – Sensitivity analysis – Equipment energy consumption – Input data

	Base power consumption (kWh/year)	Minimum power consumption (kWh/year)	Maximum power consumption (kWh/year)	Comment
Laptops	30.96	24.768	56	- 20% was applied by default for the minimum value
Tablets	19.4	10	23.28	+ 20% was applied by default for the maximum value
Smartphones	3.9	3.12	4.68	No other sources, a +- 20% was applied by default
Feature phones	0.09	0.624	1.5	- 20% was applied by default for the minimum value
Desktops	104.39	83.512	125.268	No other sources, a +- 20% was applied by default
Monitors	70	56	84	No other sources, a +- 20% was applied by default
TV	179	143.2	214.8	No other sources, a +- 20% was applied by default
Projectors	200	160	240	No other sources, a +- 20% was applied by default
TV boxes	73	58.4	87.6	No other sources, a +- 20% was applied by default
Landline phones	17.57	14.056	21.084	No other sources, a +- 20% was applied by default
Desktop consoles	55.88	44.704	67.056	No other sources, a +- 20% was applied by default
Portable consoles	5.15	4.12	6.18	No other sources, a +- 20% was applied by default
Connected speakers	23	18.4	27.6	No other sources, a +- 20% was applied by default
External HDD	0.29	0.232	0.348	No other sources, a +- 20% was applied by default
External SSD	0.1	0.08	0.12	No other sources, a +- 20% was applied by default
USB keys	0.04	0.032	0.048	No other sources, a +- 20% was applied by default
Printers	Depends on the device see Appendix Data Used in the LCA model > Printers	Depends on the device see Appendix Data Used in the LCA model > Printers	Depends on the device see Appendix Data Used in the LCA model > Printers	No other sources, a +- 20% was applied by default
Other screens	Depends on the device see Appendix Data Used in the LCA model > Electronic displays	Depends on the device see Appendix Data Used in the LCA model > Electronic displays	Depends on the device see Appendix Data Used in the LCA model > Electronic displays	No other sources, a +- 20% was applied by default
Docking stations	1.28	1.024	1.536	No other sources, a +- 20% was applied by default
IoT	Depends on the device see Appendix Data Used in the LCA model > IoT connected objects	Depends on the device see Appendix Data Used in the LCA model > IoT connected objects	Depends on the device see Appendix Data Used in the LCA model > IoT connected objects	No other sources, a +- 20% was applied by default

Results are as follow:

Table 44 – Sensitivity analysis – Equipment energy consumption – Results

	Base case	Min.	Max.
Resource use, minerals and metals	100.0%	100.0%	100.0%
Resource use, fossils	100.0%	91.1%	109.9%
Acidification	100.0%	92.7%	108.2%
Ecotoxicity, freshwater	100.0%	94.1%	106.5%
Climate change	100.0%	92.7%	108.2%
Ionising radiation, human health	100.0%	92.4%	108.4%
Particulate matter	100.0%	91.9%	109.0%
Photochemical ozone formation - human health	100.0%	93.2%	107.5%
Raw materials	100.0%	94.3%	106.4%
Waste production	100.0%	97.8%	102.5%
Primary energy consumption	100.0%	90.0%	111.1%
Final energy consumption (use)	100.0%	87.3%	114.2%

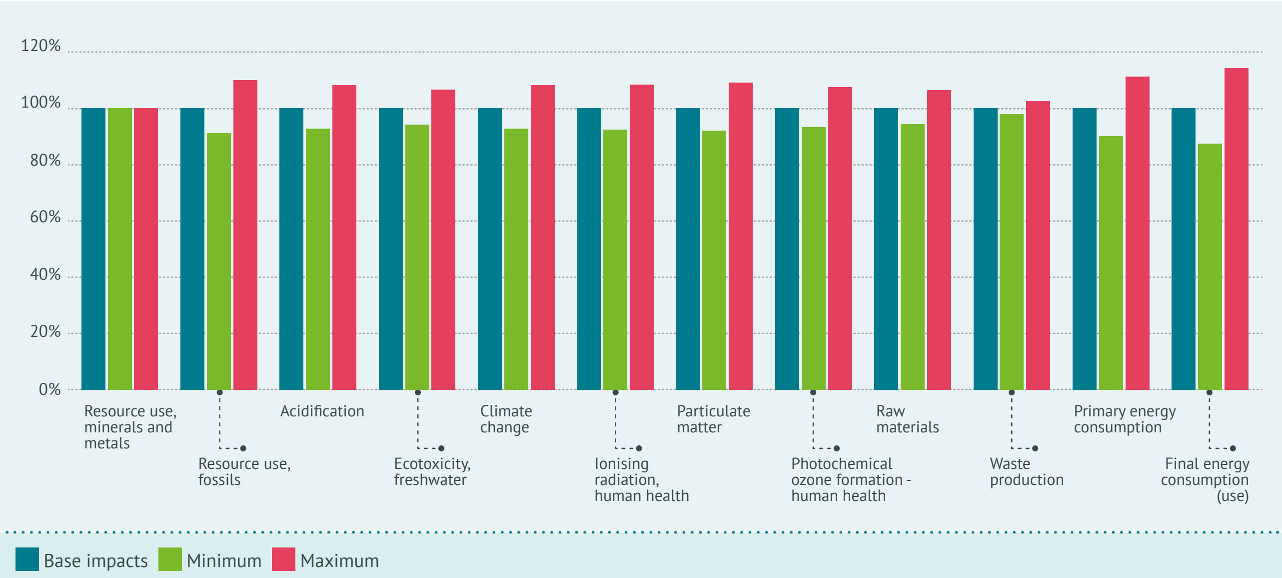
Modifying the networks' electricity consumption changes results on a range going from 87% to 114% overall. The electricity consumption of end-user devices is a key factor in the impact of digital services in the EU-28.

Specifically, for climate change, total impacts are as follow:

Table 45 – Sensitivity analysis – Equipment energy consumption – Focus on climate change

	Base impacts	Min.	Max.
Total climate change for EU28 (Mt CO_2 eq.)	185	172	200
Climate change for one EU28 inhabitant (kg CO_2 eq.)	361	334	390

Figure 5 – Sensitivity analysis – Equipment energy consumption



5.3—Sensitivity analysis on networks

5.3.1—Sensitivity analysis on electricity consumption

The electricity consumption of networks is still under discussion. There are three values in this report:

- Mobile network's electricity consumption: the base value is 15.17 TWh. Plus and minus 20% values have been considered as an assumption, meaning 12.14 TWh to 18.2 TWh.

- Fixed-line network, backbone and aggregation electricity consumption: the base value is 17.7 TWh. Plus and minus 20% values have been considered as an assumption, meaning 14.16 TWh to 21.24 TWh.

- Fixed-line networks and end-users' modems' electricity consumption: the base value is 17.92 TWh. Minimum value is based on ICT impact study[39] at 14.28 TWh, and maximum value considers plus 20% as a basic assumption, meaning up to 21.5 TWh.

Results are as follow:

Table 46 – Sensitivity analysis – Networks' electricity consumption – Results

	Base case	Min.	Max.
Resource use, minerals and metals	100.0%	100.0%	100.0%
Resource use, fossils	100.0%	97.5%	102.5%
Acidification	100.0%	97.9%	102.1%
Ecotoxicity, freshwater	100.0%	98.3%	101.7%
Climate change	100.0%	97.9%	102.1%
Ionising radiation, human health	100.0%	97.9%	102.1%
Particulate matter	100.0%	97.7%	102.3%
Photochemical ozone formation - human health	100.0%	98.1%	101.9%
Raw materials	100.0%	98.4%	101.6%
Waste production	100.0%	99.4%	100.6%
Primary energy consumption	100.0%	97.2%	102.8%
Final energy consumption (use)	100.0%	96.4%	103.6%

Modifying the number of devices changes results on a range going from 96% to 103% globally. It shows that networks' electricity consumption has a limited effect on EU-28's digital impacts as a whole.

Specifically, for climate change, total impacts are as follow:

Table 47 – Sensitivity analysis – Networks' electricity consumption – Focus on climate change

	Base impacts	Min.	Max.
Total climate change for EU28 (Mt CO_2 eq.)	185	181	189
Climate change for one EU28 inhabitant (kg CO_2 eq.)	361	353	368

5.3.2—Sensitivity analysis extrapolation to EU-28

The extrapolation from a French scenario to an EU-28 scenario was based on two parameters (cf. appendix Modelling approach, p.39 of the document Appendices of the report):

- Number of fixed-line subscribers
- Volume of transferred data

This extrapolation can lead to discussions, and other extrapolations rules could be considered. This part aims to test out other extrapolation rules:

- GDP: GDP is an indicator of produced goods and services within a country or a region. Digital activities are goods and services, therefore, GDP could be considered as an extrapolation rule. In 2019, EU-28's GDP was $15.634 trillion[40], and that same year, the French GDP was $2.716 trillion[41].

- Number of inhabitants: ultimately, inhabitants of the EU-28 are the network's users and potential users, and it is designed to fulfil their needs. There were a total of 513,500,000 inhabitants in the

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39 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.VII. Available at: <https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf> [Accessed 30 September 2021].

40 Data.worldbank.org. 2021. *GDP (current US$) - European Union | Data.* [online] Available at: <https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=EU> [Accessed 30 September 2021].

41 Data.worldbank.org. 2021. *GDP (current US$) - France | Data.* [online] Available at: <https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=FR> [Accessed 30 September 2021].

EU-28 in 2019[42]. In France, there were 66,978,000 inhabitant that same year.[43]

- DESI (Digital Economy and Society Index): this indicator is developed by the European Commission[44]. It is a composite index that has been published every year by the European Commission since 2014, measuring the progress of EU countries towards a digital economy and society. Values are considered taking only parameters 1. Connectivity, and 3. Use of internet into account. Cumulated results are: 1.945% for EU-28 and 1.949% for France. Due to the insignificant difference, this extrapolation rule has not been assessed any further.

Results are as follow:

Table 48 - Sensitivity analysis – Extrapolation to EU-28 – Results

	Base case	Sensitivity analysis - GDP	Sensitivity analysis - Inhabitants
Resource use, minerals and metals	100.0%	99.3%	101.0%
Resource use, fossils	100.0%	99.9%	100.1%
Acidification	100.0%	99.8%	100.2%
Ecotoxicity, freshwater	100.0%	99.8%	100.3%
Climate change	100.0%	99.8%	100.2%
Ionising radiation, human health	100.0%	99.6%	100.5%
Particulate matter	100.0%	99.8%	100.2%
Photochemical ozone formation - human health	100.0%	99.8%	100.2%
Raw materials	100.0%	99.5%	100.6%
Waste production	100.0%	99.4%	100.9%
Primary energy consumption	100.0%	99.9%	100.1%
Final energy consumption (use)	100.0%	100.0%	100.0%

Modifying the extrapolation to EU-28 rule changes results on a range going from 99% to 101% globally. For networks, the choice of rule-extrapolation has little impact on digital services at an overall level.

Specifically, for climate change, total impacts are as follow:

Table 49 – Sensitivity analysis – Extrapolation to EU-28 – Focus on climate change

	Base impacts	GDP	Inhabit-ants
Total climate change for EU28 (Mt CO_2 eq.)	185	185	186
Climate change for one EU28 inhabitant (kg CO_2 eq.)	361	360	361

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42 2019. Eurostat news release. *EU population up to over 513 million on 1 January 2019.* [online] Available at: <https://ec.europa.eu/eurostat/documents/2995521/9967985/3-10072019-BP-EN.pdf/e152399b-cb9e-4a42-a155-c5de6dfe25d1> [Accessed 30 September 2021].

43 Insee.fr. 2020. *Bilan démographique 2019 - Insee Première - 1789.* [online] Available at: <https://www.insee.fr/fr/statistiques/4281618> [Accessed 30 September 2021].

44 European Commission - European Commission. 2019. *Press corner.* [online] Available at: <https://ec.europa.eu/commission/presscorner/detail/en/MEMO_19_2933> [Accessed 30 September 2021].

5.4—Sensitivity analysis on data centres

5.4.1—Uncertainties analysis on energy consumption

The total energy consumption from datacentres is subject to discussions, as different sources provide different values. It can be the consequence of either a different approach or a difference in perimeter, leading to possible uncertainties (e.g. inclusion of server rooms).

The minimal and maximal values found in literature are summarized in the table below:

Table 50 – Sensitivity analysis – Energy consumption of data centres – Input data

Cases	Base case	Minimum	Maximum
Sources	Borderstep (EU-28 in 2019)[i]	ICT impact study (EU-27 in 2020)[ii]	JRC interpolated from 2015-2020 to obtain 2019 (EU-28)[iii]
Data centres electricity consumption (TWh)	79.98	39.54	98

[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.

[ii] 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.VII. Available at: *<https://circabc.europa.eu/sd/a/8b7319ba-ce4f-49ea-a6e6-b28df00b20d1/ICT%20impact%20study%20final.pdf>* [Accessed 30 September 2021].

[iii] 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

Results are as follow:

Table 51 - Sensitivity analysis – Energy consumption of data centres – Results

	Base case	Min.	Max.
Resource use, minerals and metals	100.0%	100.0%	100.0%
Resource use, fossils	100.0%	90.0%	116.0%
Acidification	100.0%	91.8%	112.9%
Ecotoxicity, freshwater	100.0%	93.4%	110.2%
Climate change	100.0%	91.8%	113.0%
Ionising radiation, human health	100.0%	91.5%	113.4%
Particulate matter	100.0%	90.9%	114.5%
Photochemical ozone formation - human health	100.0%	92.4%	111.9%
Raw materials	100.0%	93.6%	109.9%
Waste production	100.0%	97.5%	103.7%
Primary energy consumption	100.0%	88.8%	118.2%
Final energy consumption (use)	100.0%	85.7%	124.1%

Modifying the number of devices changes results on a range going from 86% to 124% overall. Reducing electricity consumption leads to a direct and significant reduction of impacts. Data centres' electricity consumption could be monitored at EU-28 scale in order to have a more precise vision.

Specifically, for climate change, total impacts are as follow:

Table 52 – Sensitivity analysis – Energy consumption of data centres – Focus on climate change

	Base impacts	Min.	Max.
Total climate change for EU28 (Mt CO_2 eq.)	185	170	192
Climate change for one EU28 inhabitant (kg CO_2 eq.)	361	331	374

5.5—Cumulative sensitivity analysis

This part will aggregate all sensitivity analyses in order to give an overview of impacts. It will allow to consider minimum and maximum environmental impacts with greater precision.

Results are as follow:

Table 53 – Sensitivity analysis – Cumulative sensitivity analysis – Results

	Base case	Min.	Max.
Resource use, minerals and metals	100.0%	76.0%	156.7%
Resource use, fossils	100.0%	69.8%	156.1%
Acidification	100.0%	71.0%	155.4%
Ecotoxicity, freshwater	100.0%	71.9%	155.4%
Climate change	100.0%	71.1%	156.6%
Ionising radiation, human health	100.0%	70.3%	145.2%
Particulate matter	100.0%	70.3%	153.1%
Photochemical ozone formation - human health	100.0%	71.5%	155.3%
Raw materials	100.0%	72.5%	154.4%
Waste production	100.0%	74.5%	155.6%
Primary energy consumption	100.0%	68.9%	156.0%
Final energy consumption (use)	100.0%	66.2%	156.3%

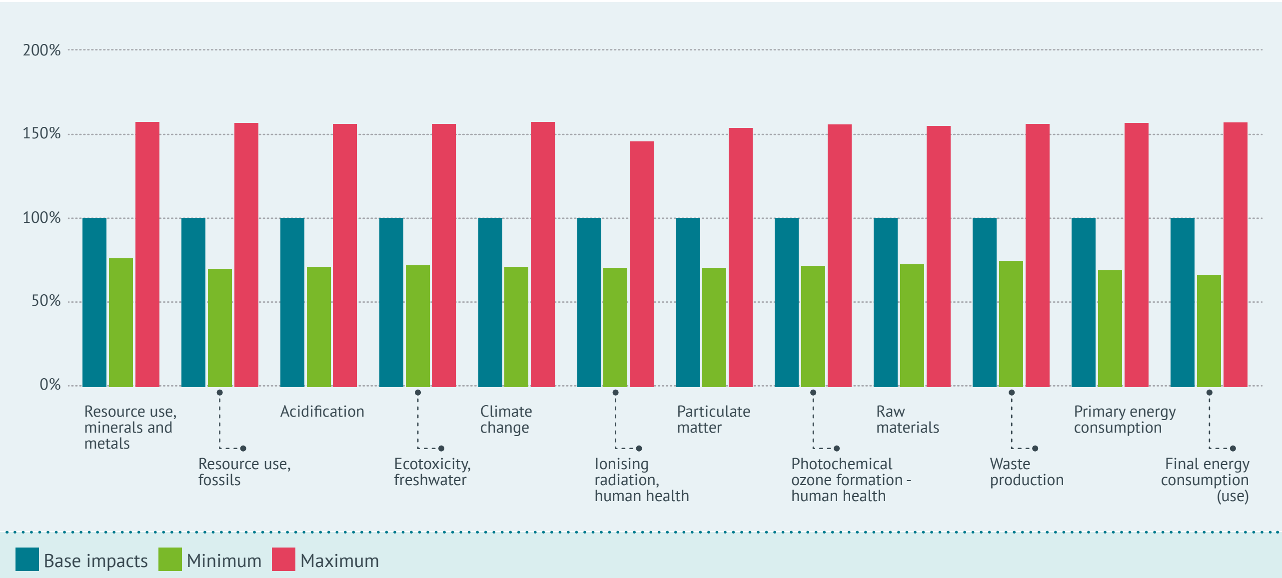
Cumulative sensitivity analysis changes results on a range going from 66% to 157% overall. It shows the extent of the possible impacts of digital services, within the scope anticipated for this study.

Specifically, for climate change, total impacts are as follow:

Table 54 – Sensitivity analysis – Cumulative sensitivity analysis – Focus on climate change

	Base impacts	Min.	Max.
Total climate change for the EU28 (Mt CO_2 eq.)	185	132	290
Climate change for one EU28 inhabitant (kg CO_2 eq.)	361	257	565

Figure 6 – Sensitivity analysis – Cumulative sensitivity analysis



6. Conclusions

The aim of this study was to assess the environmental impacts of ICT at the scale of the European Union for policy-makers and public knowledge.

In this context, the goal of this study was to provide the Greens / EFA, European citizens, as well as key stakeholders, with:

1. Clear, updated data on the environmental impact of ICT at the scale of Europe

2. A robust, objective and science-based methodology and calculation of the environmental impacts of ICT, relying on a Life Cycle Analysis

3. Policy recommendations for digital development compatible with the Green Deal

To address at best this request, our study proposes a multicriteria life cycle assessment, complying as much as possible with ISO 14040:2006 and ISO 14044:2006, and with normalisation to allow a comparison with planetary boundaries.

Multicriteria life cycle assessment key findings

Regarding the first point, global results for the environmental impacts of one year of digital services in Europe, EU-28 are presented in the following table:

Table 55 - Overall impacts of EU-28 digital services impacts (environmental impacts & flow indicators)

Resource use, minerals and metals - tonnes Sb eq.	5,760
Resource use, fossils- PJ	3,960
Acidification - mol H+ eq. (in billions)	1.19
Ecotoxicity, freshwater - CTUe	3,090
Climate change - Mt CO_2 eq.	185
Ionising radiation, human health - GBq U235 eq.	278
Particulate matter - Disease occurrence	8,000
Photochemical ozone formation - human health - tonnes NMVOC eq.	464,000
Raw materials - Mt	571
Waste production - Mt	116
Primary energy consumption - PJ	4,230
Final energy consumption (use) - PJ	1,020

Climate change, specifically, equals 185 Mt CO_2 eq.

This is the equivalent of:

- 111 t of gold in terms of rarity for resource use, mineral and metals, and 571 Mt of displaced materials, equivalent to the weight of 9.20 billion humans (averaging 62 kg). This means that each year, EU-28's digital services' related displaced materials, roughly equals to the weight of all human beings.
- Climate change impacts' are similar to 370,000 round trips of a 500 passenger-equivalent plane between Paris and New York, or about 63 years of the actual liaison (16 planes per day)
- Waste production is equal to the weight of 1.87 billion humans (averaging 62 kg)
- Electricity consumption is equal to 32,344,000 heaters (1,000 W) powered non-stop for a year.

In addition, at an EU-28 scale:

- Total electricity consumption for digital services in Europe is 283 TWh out of a total of 3,054[45] TWh, which means that electricity consumption for digital services during the use phase accounts for 9.3% of European electricity consumption.
- Total GHG emissions for digital services in Europe are 185 Mt CO_2 eq. out of a total of 4,378 Mt CO_2 eq.[46], which means that GHG emissions from digital services account for 4.2% of the European GHG emissions.

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45 IEA. 2021. *Data & Statistics - IEA*. [online] Available at: <https://www.iea.org/data-and-statistics/data-browser?country=EU28&fuel=Electricity%20and%20heat&indicator=TotElecCons> [Accessed 30 September 2021].

46 EEA. 2021. *Data viewer on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU Member States)*. [online] Available at: <https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer> [Accessed 30 September 2021].

Note

The EU-28 scale comparisons are aimed at providing a scale of related impacts and must not be understood as absolute results. The perimeters are different: some emissions related to digital services in the EU-28 occur outside EU-28 and are considered within the scope of the study (manufacturing of the devices); while the total emissions considered for the EU by the IEA are only emissions occurring within EU borders.

To learn more about imported emissions: https://www.idhsustainabletrade.com/news/hidden-CO2-emissions-europes-imported-responsibility/

Impacts reduced to one European inhabitant are:

Table 56 - Digital services impacts per EU-28 inhabitant (environmental impacts & flow indicators)

Resource use, minerals and metals - g Sb eq.	11.2
Resource use, fossils- MJ	7,710
Acidification - mol H+ eq.	2
Ecotoxicity, freshwater - CTUe	6,010
Climate change - kg CO_2 eq.	361
Ionising radiation, human health - kBq U235 eq.	541
Particulate matter - Disease occurrence	0.00156%
Photochemical ozone formation - human health - kg NMVOC eq.	0.91
Raw materials - kg	1,110
Waste production - kg	225
Primary energy consumption - MJ	8,230
Final energy consumption (use) - MJ	1,980

Climate change, specifically, equals 361 kg CO_2 eq. for one EU-28 inhabitant.

This is the equivalent of:

- In terms of climate change impacts: similar to 1 round-trip of a plane passenger between Paris and Athens.
- Resource use, mineral and metals: 0.69 kg of tin in terms or rarity, and 1,110 kg of displaced materials, equivalent to the weight of 18 humans (averaging 62 kg).
- Waste production: 225 kg of global waste, equivalent to the weight of 3.6 humans (averaging 62 kg).
- Electricity consumption: 1 heater (1,000W) powered non-stop for 23 days.

The results of this study show the importance of using a multi-criteria approach to study the environmental impacts in the case of digital technology. Indeed, it is observed that although the impacts on climate change are significant (185 MtCO_2eq.), other indicators also show very high rates, in particular the use of resources (minerals, metals and fossils). Especially as they remain preponderant after normalisation and weighting of the impacts, they should therefore be taken into account first and foremost in all strategies to reduce environmental impacts, and in order to avoid transfers of impacts, which cannot be neglected in a search for environmental sustainability.

The table below details the normalised and weighted results:

Table 57 - Weighted results

Resource use, minerals and metals - kg Sb eq.	22.9%
Resource use, fossils- MJ	17.0%
Acidification - mol H+ eq.	4.5%
Ecotoxicity, freshwater - CTUe	4.7%
Climate change - kg CO_2 eq.	16.2%
Ionising radiation, human health - kBq U235 eq.	11.1%
Particulate matter - Disease occurrence	4.0%
Photochemical ozone formation - human health - kg NMVOC eq.	1.8%
Raw materials - kg	No weighting factors
Waste production - kg	
Primary energy consumption - MJ	
Final energy consumption (use) - MJ	

Limits of the study

Providing an exhaustive and precise environmental assessment of digital services in the European Union at an institutional level is a complex exercise facing some limitations. These are due to:

- a constant evolution in technological development and use at individual and industrial levels considering, as well as devices, networks and data centres (e.g. change in screen technologies, development of new of network types every 5-7 years, development of new technologies and use: IoT, cloud computing, edge computing...)

- a limited access to qualitative data,
- a lack in transparency in the scope of reported data. Digital services are a recent part of the current economy and the awareness around environmental issues associated to digital technology is both recent and not subject to reporting requirements,
- discrepancies in data sources (institutional and industrial ones) that generates unqualifiable uncertainties.

Therefore, these chapters aim to identify and qualify the limitations to acknowledge them and anticipate future potential updates. Indeed, this study is a first step to help enrich our knowledge when it comes to qualifying the environmental impacts of digital services. It also aims to offer recommendations to better manage the footprint of the European digital services.

Limitations associated to the scope of the study

Digital services outside the European Union

The study takes into account the devices installed on EU-28 ground: end-user devices, networks, and data centres.

Regarding networks and data centres, it does not account for any abroad equipment used for digital services within EU-28, but takes into account all equipment within borders, even for digital services used outside the EU-28. We considered that the balance between abroad and inside installed equipment was fair.

In order to go further on, complementary investigation should be lead.

Consideration on maintenance, upgrade, and remanufacturing

During use phase, some devices require maintenance (parts' changing, cleaning, etc.), and some can be upgraded (for example desktops). The spares and maintenance activities impacts were not integrated.

Besides, in this study we considered a linear economy model (produce, use, discard) that is predominant in ICT sector. Indeed, remanufacturing and repairing activities at the level of ICT sector are not widely deployed currently. Therefore, this phenomenon was considered as a negligible part of the industry.

However, increasing device lifespan as well as developing maintenance activities is a strategic priority to reduce the overall impact of ICT. As a consequence, these activities should be reintegrated in the scope of a future study.

Green energy, green bonds, auto-consumption, carbon offset, carbon neutrality

The electrical mix applied is the average EU-28 electrical mix provided by the IEA in its last report (2018). The same electrical mix was applied without any distinction to all the equipment in every tier of the ICT (end-user devices, network, data centres). Some companies are claiming a reduction of their impacts due to the use of green electricity production or financial mechanisms. While some have not been taken into account due to the methodological approach (such as green bonds and carbon offsets), others have not been taken into account due to lack of data, such as auto-consumption.

Carbon neutrality is not a valid approach outside international level (accordingly to the ADEME[47] and the UNEP[48]) and has therefore not been taken into account.

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47 ADEME, 2021. AVIS de l'ADEME - La neutralité carbone. [online] Available at: <https://librairie.ademe.fr/changement-climatique-et-energie/4524-avis-de-l-ademe-la-neutralite-carbone.html> [Accessed 1 October 2021].

48 2021. Les compensations carbone ne nous sauveront pas. [online] Available at: <https://www.unep.org/fr/actualites-et-recits/recit/les-compensations-carbone-ne-nous-sauveront-pas> [Accessed 1 October 2021].

Limitations associated with life cycle inventory and data collection

Data accessibility and quality assessment

The quality of an LCA study is highly dependent of the quality of the input data. A higher proportion of primary input data guaranties a higher quality of results and a reduction of results' uncertainty. Considering the magnitude of the study perimeter and the duration of the study, it was not possible to organise any on-site data collection nor to systematise the questioning of all the stakeholders of the digital sector.

As a consequence, the present study is based on a compilation of the current data available challenged by qualified experts, or based on data provided by European stakeholders, when possible. In order to limit and manage disparities in data, the following principles have been applied in relation to 5 parameters (see section Data Quality Requirements):

- **Technological representativeness:** representative of technologies between 2015 and 2020.
- **Geographical representativeness:** specific data corresponding to the digital services related equipment located in the European Union (28 states members) during their use, considering that some of their life cycle phases such as manufacturing may occur abroad (market-based approach). If data is missing, assumptions are justified when possible.
- **Time-related representativeness:** data from 2019-2020. If data is more than 5 years old (before 2015), has been updated with assumptions and justified when possible.
- **Completeness:** the application of cut-off criteria is complex considering the amount of equipment and processes. The study includes all identified flows, unless stated elsewise.
- **Parameter uncertainty:** for most of the data, only one source was available, providing a high degree of uncertainty. When possible, data has been cross-checked with additional sources.
- **Methodological appropriateness and consistency:** methodology used: ISO 14040-44. Uniform application of data collection methodology for all components under study.

This limitation applies to the devices inventory, estimate lifespan and energy consumption.

In order to increase data quality of such a study in the future, organising the monitoring of the digital industry and federating the stakeholders in the sector should be considered: manufacturers, distributors, Internet access providers and service providers could all be part of organising feedback of precise information. Such information can be used to better monitor the deployment of digital technology in Europe.

Lack in collected data

Pieces of equipment and networks have been identified as part of the scope of the digital area but have not been integrated in the scope of the study, due to lack of accessible data. It is the case of satellite and terrestrial TV, PSTN (Public Switched Telephone Network), DVD players, Interactive whiteboard, MP3 players, Stand-alone home audio equipment, ATM, Cash registers and POS terminals, Ticket machines, Public WLAN hotspots, Toll-related ICT, Security cameras.

Considering the high impact of end-user devices (tiers 1) in the results of our study compared to the other two tiers (network and data centres), we can assume that the impact of such devices is not negligible, as stated in the sensitivity analysis.

Some equipment were certainly underestimated, such as the satellite network, since satellite and rocket's conception and launching generate important impacts.

All these elements potentially lead to an underestimation of results. Integrating these technologies and equipment should be anticipated in future studies.

Estimated lifespan, energy consumption

Lifespan and energy consumption are highly dependent on the final service application, on the final user behaviour, on the digitalisation policy of the considered country/industry.

As a consequence, wide variations can be observed. The present study aims to present a global view of the environmental impacts of digital services. Thus, an average approach has been considered in the usage scenarios considered.

Differentiating the different usages could have allowed more accurate results, but it was not the objective of this study.

Limitations associated with indicators

Land and water use are both indicators of interest for ICT impacts, but life cycle databases are still insufficiently mature to assess impacts with enough certainty: indeed, current results are often linked to mistakes in elementary flow qualifications than established environmental impacts.

Therefore, it is important to continue to follow and stimulate the development of these indicators, but to date, no conclusion could be established regarding these indicators. ■

Appendices

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B—Glossary

Acidification

Although ocean acidification is also caused by other chemical additions and removals, CO_2 is the primary factor affecting pH. Once CO_2 is dissolved in seawater, it becomes a weak acid that primarily affects carbonate chemistry. Dissolved CO_2 increases the concentration of bicarbonate ions (HCO_3^-), dissolved inorganic carbon (CT) and lowers the pH. Freshwater also absorbs atmospheric CO_2, which can also lower the pH. In addition to CO_2, freshwater reservoir's pH values are altered by acid rain, nutrient runoff, and other anthropogenic pollutants. Freshwater uptakes CO_2 in the same mechanism as seawater, however, freshwater alkalinity is much lower than seawater, due to the absence of a salt-buffer. Due to the lack of salt-buffer, pH changes in freshwater tend to be much greater than ocean water, due to newly released H^+ ions not being buffered by as many bicarbonate (HCO_3^-) ions as ocean water. [Wikipedia]

Climate change

Large-scale shifts in weather patterns driven by human-induced emissions of greenhouse gases. The largest driver of warming is the emission of carbon dioxide and methane. Fossil fuel burning (coal, oil, and natural gas) for energy consumption is the main source of these emissions. [Authors]

Cloud computing

Cloud computing is the on-demand availability of computer system resources, especially data storage and computing power, without direct active management by the user. The term is generally used to describe data centres available to many users over the Internet. Large clouds, predominant today, often have functions distributed over multiple locations from central servers. If the connection to the user is relatively close, it may be designated an edge server. Clouds may be limited to a single organization (enterprise clouds), or be available to many organizations (public cloud). Cloud computing relies on sharing of resources to achieve coherence and economies of scale. [Cisco]

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. [ICT impact study]

Colour laser MFD printer

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. [ICT impact study]

Colour laser printer

A printer that uses laser marking technology (sometime referred to as electro-photographic) to print in multiple colours. [ICT impact study]

Connected objects

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. [IoT Analytics]

Connected speaker

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. [Authors]

Data Centre

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. [EN 50600-1]

Desktop

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. [ICT impact study]

Docking station

A dock in which the laptop is plugged-in to provide a simplified way to connect different and multiple equipment (power signalling, 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. [Authors]

Electronic displays

Display screen and associated electronics that, as its primary function, displays visual information from wired or wireless sources [COMMISSION REGULATION (EU) 2019/2021]

Eutrophication

The process by which an entire body of water, or parts of it, becomes progressively enriched with minerals and nutrients. Eutrophication in freshwater ecosystems is almost always caused by excess phosphorus. Prior to human interference, this was, and continues to be, a very slow natural process in which nutrients, especially phosphorus compounds and organic matter, accumulate in water bodies. Anthropogenic or cultural eutrophication is often a much more rapid process. The visible effect of eutrophication is often nuisance algal blooms that can cause substantial ecological degradation in water bodies and associated streams. This process may result in oxygen depletion of the water body after the bacterial degradation of the algae. [Wikipedia]

External hard drive equipment

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). [Authors]

Feature phone

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. [Authors]

Game console

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). [SRI]

Hard Disk Drive (HDD)

An electro-mechanical data storage device using magnetic storage and one or more rigid rapidly rotating platters coated with magnetic material. [Authors]

Heating, Ventilation and Air Conditioning (HVAC)

HVAC refers to the industry standard technology that provides heating, cooling and air quality services to buildings and vehicles. [ICT impact study]

Human toxicity

Toxicity is the degree to which a chemical substance or a particular mixture of substances can damage an organism. The types of toxicities where substances may cause lethality to the entire body, lethality to specific organs, major/minor damage, or cause cancer. These are globally accepted definitions of what toxicity is. Toxicity of a substance can be affected by many different factors, such as the pathway of administration (whether the toxicant is applied to the skin, ingested, inhaled, injected), the time of exposure (a brief encounter or long term), the number of exposures (a single dose or multiple doses over time), the physical form of the toxicant (solid, liquid, gas), the genetic makeup of an individual, an individual's overall health, and many others. [Wikipedia]

Ink jet MFD printer

A multi-functional printer, that can copy, scan and print, that uses Inkjet marking technology to print in several colours. [ICT impact study]

Ink jet printer

A printer that uses inkjet marking technology to print in multiple colours. [ICT impact study]

Internet of Things (IoT)

The IoT refers to the global network of smart devices, vehicles, buildings and other objects embedded with intelligent software and sensors that enable these items to communicate and collect data. [ICT impact study]

Ionising radiation

Ionizing radiation (ionising radiation) consists of subatomic particles or electromagnetic waves that have sufficient energy to ionize atoms or molecules by detaching electrons from them. Ionizing radiation is not detectable by human senses, so instruments such as Geiger counters must be used to detect and measure it. Exposure to ionizing radiation causes cell damage to living tissue. In high acute doses, it will result in radiation burns and radiation sickness, and lower level doses over a protracted time can cause cancer. [Wikipedia]

Land line phone

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. [ICT impact study]

Land use

Land-use change can be a factor in CO2 (carbon dioxide) atmospheric concentration, and is thus a contributor to global climate change. The impact of land-use change on the climate is more and more recognized by the climate community. Additionally, land use is of critical importance for biodiversity. The extent, and type of land use directly affects wildlife habitat and thereby impacts local and global biodiversity. Human alteration of landscapes from natural vegetation (e.g. wilderness) to any other use can result in habitat loss, degradation, and fragmentation, all of which can have devastating effects on biodiversity. Land conversion is the single greatest cause of extinction of terrestrial species. [Wikipedia]

Laptop

Also designated as notebook, 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. [ICT impact study]

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. [JRC]

Mobile phone

A mobile phone or cell phone 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. [Authors]

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. [ICT impact study]

Mono laser MDF printer

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. [ICT impact study]

Mono laser printer

A printer that uses laser marking technology (sometime referred to as electro-photographic) to print in one colour only. [ICT impact study]

Network

A network is a group of computer systems linked together. Types of networks include Local Area Network (LAN), Wide Area Network (WAN), Wireless Local Area Network (WLAN), Storage Area Network (SAN) and Metro Area Network (MAN). Networks may be further categorized based on topology, protocol and architecture. [ICT impact study]

Ozone depletion

Phenomenon observed since the late 1970s including both a steady lowering of the total amount of ozone in Earth's atmosphere (ozone layer) and a decrease in stratospheric ozone around Earth's polar region, referred to as the ozone hole. Manufactured chemicals, especially halocarbon refrigerants, solvents, propellant, and foam-blowing agents are the main causes of ozone depletion and are referred to as ozone-depleting substances (ODS). [Authors]

Particulate matter

Also designated as particulates, atmospheric aerosol particles or suspended particulate matter (SPM), are microscopic particles of solid or liquid matter suspended in the air. Their impact on climate and precipitation affect human health, in ways additional to direct inhalation. [Authors]

Photochemical ozone formation

Ground level or tropospheric ozone is created by chemical reactions between oxides of nitrogen (NOx gases) and volatile organic compounds (VOCs). The combination of these chemicals in the presence of sunlight form ozone. Its concentration increases as height above sea level increases, with a maximum concentration at the tropopause. About 90% of total ozone in the atmosphere is in the stratosphere, and 10% is in the troposphere. Although tropospheric ozone is less concentrated than stratospheric ozone, it is of concern because of its health effects. Ozone in the troposphere is considered a greenhouse gas, and may contribute to global warming. [Wikipedia]

Power Usage Effectiveness (PUE)

PUE is an energy efficiency metric developed by a consortium known as 'The Green Grid'. It measures the ratio of total power consumed by a data centre relative to the power used to run its IT equipment. [ICT impact study]

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. [ICT impact study]

Projector

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. [ICT impact study]

Rack

A metal framed chassis that holds, secures and organizes a vertical stack of network and server hardware, including routers, switches, access points, storage devices and modems. Also known as a cabinet. [ICT impact study]

Renewable energy

Useful energy collected from renewable resources (meaning these resources are naturally replenish on a human timescale). Renewable resources include sunlight, wind, rain, tides, waves and geothermal heat. [Authors]

Resource use, fossils, minerals and metals

Resource extraction involves any activity that withdraws resources from nature. In regard to natural resources, depletion is of concern for sustainable development as it has the ability to degrade current environments and the potential to impact the needs of future generations. The depletion of natural resources is caused by 'direct drivers of change' such as mining, petroleum extraction. [Wikipedia]

Scanner

A product whose primary function is to convert paper originals into electronic images that can be stored, edited converted or transmitted. [ICT impact study]

Smartphone

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. [Authors]

Solid-State Drive

An electro-mechanical data storage device using integrated circuit assemblies to store data in semiconductor cells. [Authors]

Tablet

A product which is a type of notebook computer that includes both an attached touch-sensitive display and can have an attached physical keyboard. [ICT impact study]

TV box

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

Uninterruptible Power Supply (UPS)

A UPS is a device that provides emergency power when the primary power source fails, allowing equipment to continue to operate for a limited time. It can also provide protection from power surges. [ICT impact study]

USB key

A memory-based USB drive, or USB flash drive uses integrated circuit assemblies to store data in semiconductor cells like SSD, but with lower capacities. [Authors]

Water use

Environmental consequences of water consumption, regarding description of transport flow between water compartments (e.g. from river to atmosphere via evaporation) and regions. [Authors]

Computer Room Air Conditioners (CRAC)

Computer Room Air Conditioners (CRACs) provides perimeter cooling for datacentre halls and server rooms. More than one CRAC unit can be installed within the area and units can be arranged in an N+X parallel/redundant configuration to provide added resilience. CRAC units use a refrigerant as the cooling medium. Computer Room Air Handlers (CRAHs) can be installed in a similar type of installation to CRAC units but use chilled water as their cooling medium. Internal cooling fans and coils are used to provide cool air into the datacentre environment. Other technologies can include Indirect adiabatic cooling (IAC) and free air cooling and may be more bespoke than standard manufactured product ranges. [Server Room Environment[1]]

1 https://www.serverroomenvironments.co.uk/computer-room-air-conditioners

C—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

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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

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)

D—Index of tables

E—Index of figures

THE GREENS/EFA
in the European Parliament

60 rue Wiertz/Wiertzstraat 60
1047 Brussels, Belgium
www.greens-efa.eu
contactgreens@ep.europa.eu