WHAT IS THE ENVIRONMENTAL FOOTPRINT OF A TERMINAL AT DIFFERENT STAGES OF ITS LIFE CYCLE?

Authors and date

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INTRODUCTION

The environmental impacts associated with computer hardware are not limited to the effects of their electricity consumption when they are used, far from it! Assessing these impacts requires taking into account the entire **life cycle** of the device: its production, distribution, use and end of life.

In addition, there are **different types of impacts**: reduction of exploitable mineral resources, water consumption, various types of pollution, without forgetting of course the environmental impacts linked to the production of the energy used throughout the life cycle.

In this article, we introduce the case of terminals (desktop computers with screens, laptops, smartphones, tablets...), for which the production phase concentrates a **large part of the environmental impacts**, including those related to the energy consumption of the devices (see figures 1, 2 and 3).

Note: The figures presented throughout this article are intended to provide an order of magnitude of environmental impacts rather than precise values. Many are obtained by conducting **Life Cycle Assessments** (LCA), which are complex processes and require careful consideration to understand the results. More information can be found at **Concept sheet "Life cycle assessment applied to digital services"** .

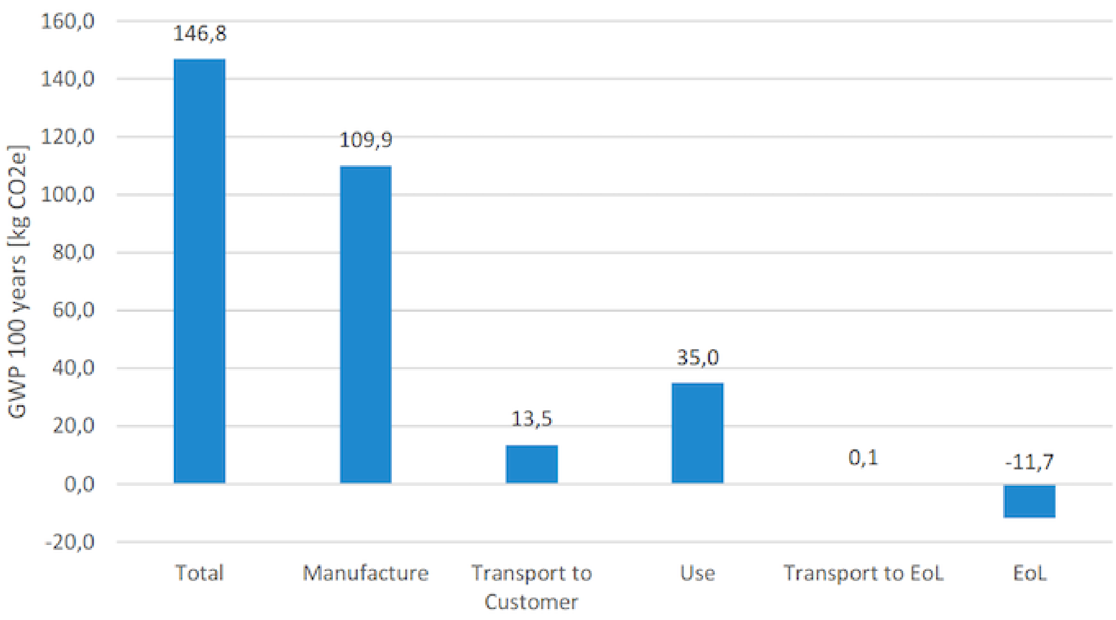

Figure 1: Contribution to the Global Warming Potential (*GWP: Global Warming Potential*), expressed in Kg CO2e at 100 years, of the different life cycle phases of a Dell 7300 **laptop** used in Europe [1] [2]. This category of impact is directly linked to energy aspects, hence the importance of specifying the region of use because the energy mix is not the same everywhere. We can see that the production phase (*Manufacture*) predominates. The end of life (*EoL: End of Life*) is negative because of the energy recovered during this phase, for example by incineration of plastic parts.

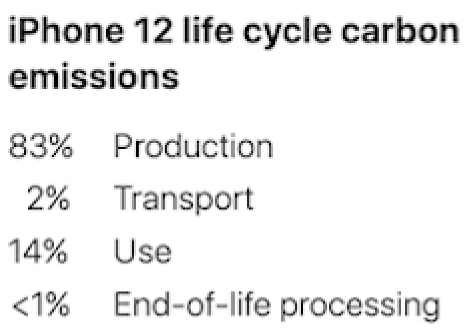

Figure 2: Contribution to the global warming potential of the different phases of the life cycle of a **smartphone**, in this case the Apple iPhone 12, used in the United States [3]. In the case of smartphones, the production phase accounts for an even larger share of the impacts.

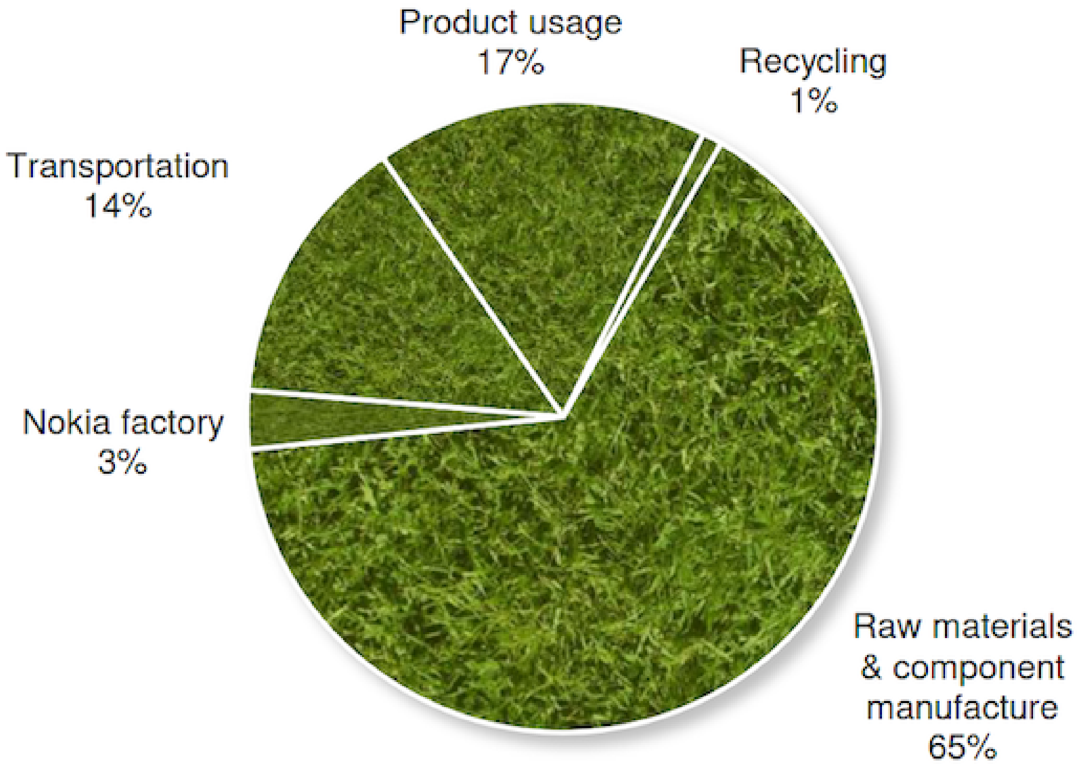

Figure 3: Contribution to the global warming potential of the different phases of the life cycle of a Nokia Lumia 820 **smartphone** (region of use not specified) [4]. It can be seen that the assembly of components by the manufacturer has a minor impact compared to the extraction of raw materials (*Raw materials*) and the manufacture of components (*Component manufacture*).

THE PRODUCTION PHASE

The production phase starts with the extraction of raw materials and ends with the manufacture of the good, including intermediate steps such as the processing of raw materials, the manufacture of components and their transport.

COMPONENTS WITH A HIGH ENVIRONMENTAL IMPACT

A terminal is mainly made up of metals, plastics and ceramic materials (especially glass). More than fifty different metals are present in a computer or smartphone, some (copper, iron, aluminum) for so-called structural functions, and others for technological functions. Among the latter, we find minor metals (according to an economic classification of metals) such as tantalum, indium, lithium and cobalt. There are also precious metals in small quantities (silver, gold, palladium). More information can be found at **Concept sheet "Which metals are in smartphones?"** .

Among the elements that make up a terminal, those whose production has the greatest impact are the electronic cards (in particular the integrated circuits they support), the screens, the hard disks (for computers), and the batteries (laptops, tablets, smartphones), as illustrated in Figure 4.

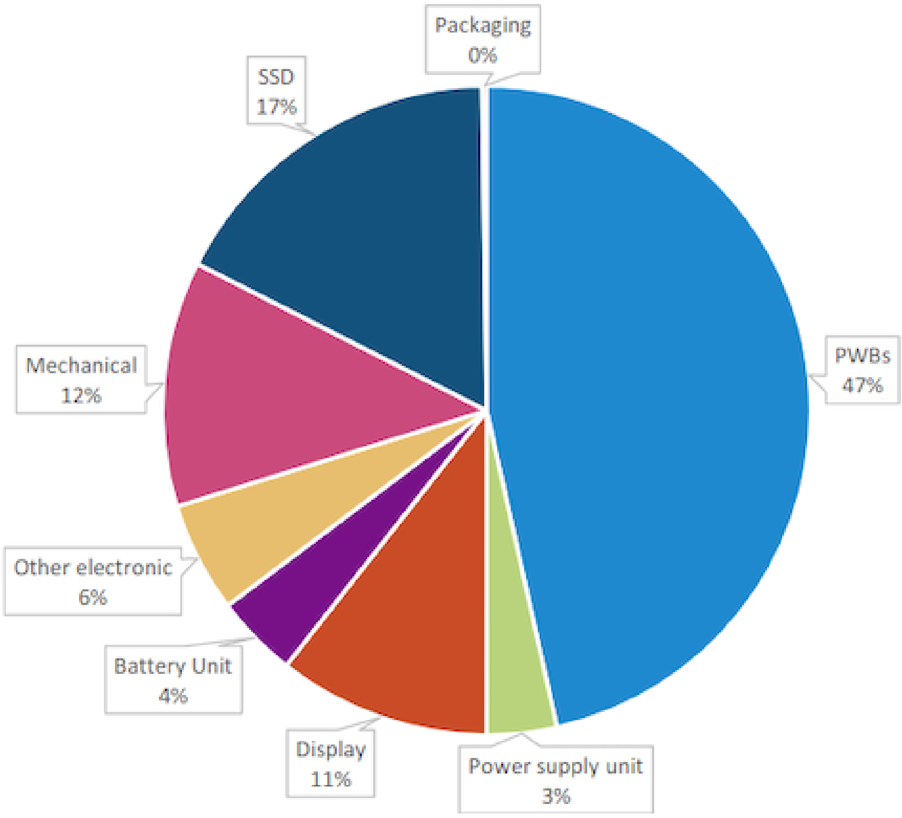

Figure 4: Contribution of individual components of a Dell 7300 laptop to global warming potential[1 2]. The electronic boards (*PWB*, for *Printed Wiring Board*) and the SSD hard drive are responsible for the majority of greenhouse gas emissions.

It should be noted that the environmental impact is almost proportional to the surface of the screen, or the size of the hard disk or the battery. In general, there is a tendency to transfer energy consumption from the use phase to the production phase: manufacturing more energy-efficient products requires more advanced technologies, which require more energy to produce and which are based on an increased number of metals, often present in very small quantities [2].

THE PRODUCTION OF METALS

The different phases of metal production are as follows: extraction of the ore, its crushing and grinding in order to separate its different components, then the concentration phase (also called enrichment) of the ore by physical and/or chemical means: gravity, magnetism, electrostatics, flotation, electrolysis, leaching (i.e. the use of solvents such as cyanide or sulphuric acid to separate the desired metals), pyrometallurgy... The associated environmental impacts and risks are considerable.

First of all, the **energy consumption** (and therefore its associated impacts) is enormous at all stages, with a great disparity between the different metals (for example 54 GJ/t on average for copper against 208,000 GJ/t for gold) [5]. This energy is necessary, among other things, to evacuate the earth and rocks (called overburden) in order to access the ore, and then to extract the phenomenal quantities of ore from which the metal is extracted, bearing in mind that the copper content of a good quality ore can be as low as 0.25 to 0.50 %, (a few hundredths of a percent for a good quality gold ore) [6]. In total, it is estimated that about 10% of the world's primary energy is used to extract, transport and refine metal resources (all sectors combined) [5].

A copper mine in central Romania (source: Cristian Bortes, CC BY 2.0, via Wikimedia Commons). The majority of mines are open-pit mines, as opposed to underground mines (which although a minority are nevertheless numerous).

Secondly, mining is an activity that requires a **massive amount of water**, mainly for the crushing and concentration phases of the ore. According to the *Columbia Center on Sustainable Investment*, about 70% of the mining operations of the six largest companies are located in water-stressed countries [5]. Thus, the water requirements for copper production in Peru and lithium production in Argentina, Chile and Bolivia conflict with the needs of local populations.

On the other hand, mining can lead to **severe pollution** of surface and groundwater, as well as of air and soil. This pollution is mainly due, on the one hand, to the mine tailings resulting from the concentration of the ore, which often contain toxic substances (e.g. mercury or arsenic) likely to run off in the form of mine acid, and on the other hand to the chemical products used during the ore concentration phase (e.g. cyanide leaching for gold, sulfuric acid leaching for copper)

Human impacts. Finally, it is impossible to address the issue of the environmental impacts of the extraction of metals used in digital devices without mentioning the associated geopolitical issues and their consequences on the populations of the regions concerned. For example, certain metals and the minerals from which they are produced (tantalum, which is mainly obtained from coltan, tin, tungsten and gold) are subject to a specific European regulation on conflict minerals because of the role they play in the financing of armed conflicts in certain unstable regions of the world, such as the Democratic Republic of Congo (DRC). The water-related tensions mentioned above are also a source of many conflicts in Latin America.

More generally, the reserves and production areas of certain metals are very inequitably distributed[7]: in 2019, Chile and Australia accounted for 75% of the production and 66% of the world's lithium reserves, the DRC and Rwanda 50% of tantalum production (66% in 2017) and the DRC 69% of cobalt production (and more than half of reserves). China accounted for 98% of global rare earth production in 2010, up from 60% in 2019.

A coltan mine in the Democratic Republic of Congo (source: MONUSCO Photos, CC BY-SA 2.0, via Wikimedia Commons). This mine, located in Luwowo, complies with the ICGLR-DRC standard, which guarantees minerals that are not linked to ongoing conflicts in the region.

SEMICONDUCTOR MANUFACTURING

The manufacture of semiconductors (also called integrated circuits, or simply electronic chips) is a very high-tech activity concentrated in the hands of a very small number of players. Currently, only two companies (Samsung in South Korea and TSMC in Taiwan) manufacture the latest generation of semiconductors (sub-7 nanometer technology) used in high-end smartphones.

The manufacturing process of an electronic chip can be summarized as follows: a *die* is obtained by printing a miniaturized electronic circuit (transistors, capacitors etc.) on a wafer of semiconductor material, usually silicon, called a *wafer*. The **extreme precision** required for these operations requires ultra pure materials. This affects the energy needed to produce these materials, but also involves massive use of chemicals and water. As a result, the Taiwanese company TSMC consumed over 150,000 tons of water per day in 2019[8]. The **water needs** of the semiconductor industry are a major issue for Taiwan, which faced a catastrophic drought in 2021, leading to water restrictions for residents.

THE USAGE PHASE

A terminal in use does not usually consume water [9], does not (normally) emit toxic substances... Thus, during its use phase, its direct environmental impact is limited to the impacts associated with its electricity consumption. The latter varies [10] according to the type of equipment, the use made of it, the life span of the equipment, etc. In any case, in a country like France where electricity is low in carbon (but at the cost of other environmental impacts related to the operation of nuclear power plants, not to mention the associated risks), CO2 emissions related to the use phase are relatively limited compared to the production phase.

Nevertheless, it is worth mentioning the impacts linked to the use of a device connected to a telecommunications network (Internet, 4G...), which will require network equipment and data centers to communicate, download videos, access websites, etc. These infrastructures also consume energy. These infrastructures also consume electricity (the usage phase representing a very large part of the energy consumption of the infrastructures) but also water for cooling, and their production has environmental consequences similar to those of the terminals presented above. This topic is addressed in **Concept sheet "Life cycle assessment applied to digital services"** .

END OF LIFE

The environmental impact of the end of life of a terminal depends obviously on what happens to the device once it is no longer in use. In general, there are many unknowns about the environmental impacts of the end-of-life of digital devices. The first reason is the lack of scientific knowledge about the toxicity and ecotoxicity of certain materials used. A second reason is the uncertainty about what happens to digital devices at the end of their life, both within dedicated treatment channels (where they are mixed with other waste electrical and electronic equipment (WEEE) such as hairdryers or kettles) and outside the regulatory framework (illegal trafficking etc.).

POLLUTION RISKS

Although the situation is improving (thanks to new regulations and the efforts of manufacturers), many materials that are potentially toxic to humans and ecosystems are present in terminals: beryllium, cadmium, nickel, mercury, arsenic, silver, antimony, chrome, lead, etc. The brominated flame retardants in some plastics are also hazardous to the environment because of the gases they emit if incinerated and the organic substances they produce if they decompose.

THE WEEE SECTOR

Digital terminals are part of electrical and electronic equipment (EEE) and at the end of their life become WEEE (waste EEE), for which a specialized treatment channel exists in order to recover or dispose of them. More information can be found at **Concept sheet "Recycling overview"** .

Major metals (copper, lead, iron, aluminum, etc.) and precious metals (gold, silver, platinum, etc.) are more than 50% recycled. On the other hand, minor metals (including rare earths) are hardly recycled at all: less than 1% for indium, neodymium, tantalum, gallium and germanium, and no recycling for other minor metals [5].

The two main technical difficulties linked to the recycling of digital metals are, on the one hand, the identification by the recycling industry of these metals, which are part of increasingly complex alloys, and, on the other hand, their separation from other metals. This is called open-loop recycling because the separation process is not perfect and some of the metals recovered are not pure enough to be reused in digital devices.

This kind of recycling requires advanced technologies and extremely expensive infrastructures (one billion dollars for the Umicore plant in Belgium, for example) and energy consumption, as well as the implementation of a complex logistic chain to transport the WEEE to the different sorting and treatment centers.

WHAT HAPPENS TO WEEE OUTSIDE THE SPECIFIC CHANNEL?

It is estimated that in 2019, only 17% of WEEE will have been taken care of by the appropriate treatment channels worldwide (54% in France) [11]. The remainder is stored in private homes, dumped in landfills, burned or illegally traded and treated in a way that does not comply with standards. As a sign of the magnitude of this problem, the illegal trade and treatment of WEEE is considered by INTERPOL as a major threat to the environment.

An infamous example of an open dumping ground where WEEE (including some from Europe) is "processed" in conditions that are catastrophic in terms of human health and the environment is in Agbogbloshie, Ghana, a suburb of Accra. The metal extraction techniques used (open burning, heating or leaching using for example cyanide salt or mercury) are often implemented without any safety measures. The result is pollution similar to that which can be found in mines: pollution of the air, of the soil (by dust deposits), of the water (by runoff) by heavy metals, dioxins, brominated compounds, etc.

Incineration of electrical cables to recover copper in Agbogbloshie, Ghana (source: Muntaka Chasant, CC BY-SA 4.0, via Wikimedia Commons).

CONCLUSION

As you can see, the environmental impacts of a personal digital device (smartphone, computer, tablet...) are far from being negligible. However, they are largely invisible to the users of these devices because most of the pollution concerns the production and end-of-life phases and affects populations and ecosystems that are geographically distant from consumers.

TO GO FURTHER

- 100 millions de téléphones portables usagés : l'urgence d'une stratégie, Rapport d'information pour le Sénat, 2016 [13/09/2021]
- Louis-Philippe P.-V.P. Clément, Quentin E.S. Jacquemotte, Lorenz M. Hilty. Sources of variation in life cycle assessments of smartphones and tablet computers [online by subscription]. Environmental Impact Assessment Review, 2020, volume 84. Available from Elsevier [09/13/2021]
- Paul Teehan, Milind Kandlikar. Sources of variation in life cycle assessments of desktop computers [online]. Journal of industrial ecology, 2012. Available from Wiley. [13/09/2021]

ON LIFE CYCLE ASSESSMENT

- Concept sheet "Life cycle assessment"

- Concept sheet "Life cycle assessment applied to digital services" .

ON METAL PRODUCTION

- Concept sheet "What metals in smartphones?"
- Concept sheet "Why is it difficult to make projections around the duration of mining reserves?"

ON WEEE

- Concept sheet "Recycling overview"
- Les enfants et les décharges numériques -- Exposition aux déchets d'équipements électriques et électroniques et santé des enfants. OMS report, 06/15/2021. [13/09/2021]

SOURCES

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1. *Life Cycle Assessment of Dell Latitude 7300*, 67 page detailed report ↩ ↩
2. *Life Cycle Assessment of Dell Latitude 7300*, 2 page summary ↩ ↩ ↩
3. *Product Environmental Report iPhone 12* ↩
4. *Nokia Lumia 820 Eco profile* ↩
5. La consommation de métaux du numérique : un secteur loin d'être dématérialisé, 08/2020 ↩ ↩ ↩ ↩
6. Guide pour l'évaluation des EIE de projets miniers ↩
7. *Mineral Commodity Summaries 2021* ↩
8. *TSMC Corporate Social Responsibility Report 2019* ↩
9. There are water cooling systems used especially for gaming PCs. ↩
10. The reader interested in this issue can refer to the work cited in the "Going Further" section around sources of variation in LCAs of smartphones, tablets and desktop computers. ↩
11. Suivi des déchets d'équipements électriques et électroniques à l'échelle mondiale pour 2020 ↩