Environmental impacts of digitalisation: what to bear in mind

Author: Alexandre Duporte.
Contributors : Gabriella Carmasa, Anabel Nava Tazo, Enrique Nieto & Robin Salter.

Digitalisation, considered as the third industrial revolution, is happening in every part of society and is one of the main components of current development strategies. New technologies increase productivity and efficiency at work and at home. However, due to the considerable environmental costs of growing demand and use, digitalisation is rather part of the problem than part of the solution nowadays. Decisions have to be taken to finally make digital tools an ally of the environmental transition.

Today, across the world there are more than 14 billion smartphones, 21 billion connected devices and 7 billion Google searches per day (Leonarduzzi 2021). Telecommunication networks, data centres, digital devices (smartphones, computers, routers…) and Internet of Things are the core of development strategies of main international organisations and national governments.

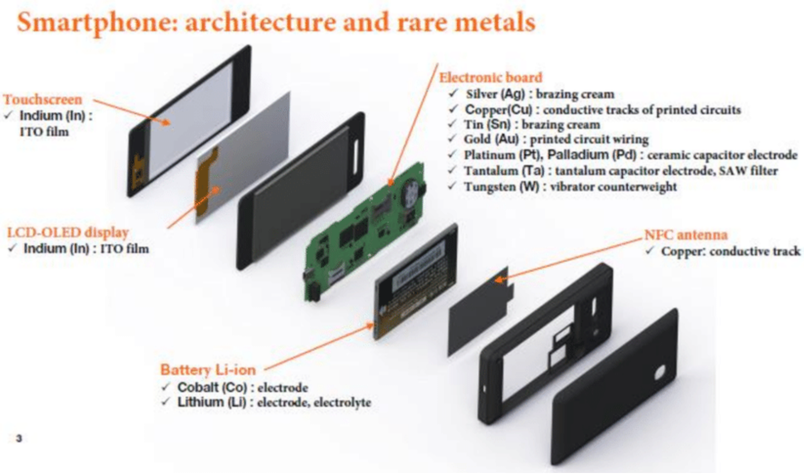
Thanks to new technologies, people and organisations can increase their productivity and efficiency, access more services and goods, ease their workload and optimise their travel, especially during the Covid pandemic. Digitalisation can also play a role in the environmental transition, in reducing energy and natural resources consumption through smart applications (smart grids, connected mobility, smart buildings, smart farming…).

That's why, to achieve the Green Deal, the European Commission relies on Information and Communication Technologies (ICT). Just like industrial value chains and green technologies, ICTs require a lot of different critical raw materials (CRM) such as indium, lithium, rare earths, tantalum, gallium, and other precious and non ferrous metals such as copper and silver. These elements have fantastic capacities that allow for a wide range of applications.

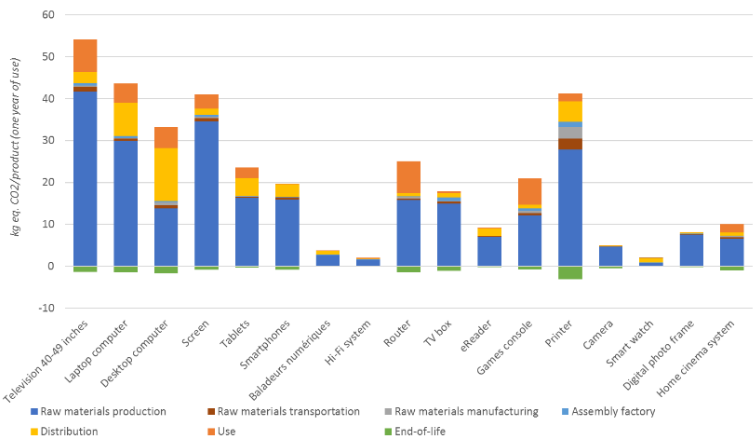
The continued growth of the global population, and the convergence of living standards, will increase the global

demand for ICTs, leading to a considerable rise in demand for raw materials between 2017 (89 Gt) and 2060 (167 Gt) (OECD 2019). The use of metallic ores - especially rare metals[1] - will more than double between 2017 (9 Gt) and 2060 (20 Gt) (Ibid, 3). Such growth in materials use is likely to worsen the state of natural resources and ecosystems, and threaten future gains in well-being. Indeed, materials use represents half of global greenhouse gases (GHG) emissions, and more than 90% of biodiversity loss and water stress (European Commission 2020a).

The overconsumption of digital applications, mainly in developed countries, is strongly linked to critical issues. Among socio-environmental[2] and geopolitical[3] impacts, the environmental ones are significantly increasing. Digitalisation is responsible for environmental pollution and degradation across the world. Besides, ICT are responsible for between 2,1% and 3,9% of GHG emissions and it is going to increase without intervention (Freitag et al. 2021). According to the IPCC (2022, TS-132): “At present, the understanding of both the direct and indirect impacts of digitalisation on energy use, carbon emissions and potential mitigation [of carbon emissions] is limited”. If not appropriately governed, digitalisation can have adverse side-effects (Ibid, SPM-12). Let’s see what impacts can digitalisation have on the environment, all along its life cycle.



Picture 1: Smartphone architecture, extract of materials (Orange Labs 2017)



Picture 2: Impact assessment of the different phases of the ICT life cycle (ADEME 2018, 17)

Production phase

Most problematic phase

ICTs need a wide range of rare metals. For example, a smartphone requires at least 40 different metals (The Shift Project 2019a, 24). Picture 1 gives an idea of the metals needed for the different components.

1 Metals of the Mendeleev’s periodic table that are rare or likely to become rare because of growth demand, end of stocks or conflicts.

2 Risks associated with critical raw materials extraction and use: pollution, water conflict with local communities, forced displacements, violation of native people rights, corruption and tax evasion, human rights violation (Saint-Aubin 2019, 17).

3 The EU depends between 75% and 100% on foreign imports for most critical metals (European Commission 2020a, 7). China holds, for instance, 90% of rare earths production and uses mineral resources as a strategic weapon, such as against Japan in 2011 (Saint-Aubin 2019, 16).

The production phase, in particular the extraction of metals, has the greatest impact on the life cycle of ICTs. It represents 45% of the energy footprint[4] of digitalisation (The Shift Project 2019a, 19). In 2018, the Agency for the Ecological Transition (ADEME), assessed the entire life cycle of various ICTs, according to four indicators: climate change, abiotic resource depletion, acidification and particle matters. It confirms that the extraction phase of raw materials has the highest impact, as illustrated in picture 2.

4 Directly linked to GHG emissions. The amount depends on the electrical mix used.

From extraction to production:
Before being assembled in a digital device, ores undertake a complex process. To get a few grams of a rare metal, around a ton of rocks have to be extracted (Systex 2021, 14). Then, rocks need to be treated through three processes: concentration, chemical extraction and refining. The ore treatment phase has the most important impacts in a mining site (extraction + treatment), representing 70% of water consumption and more than 80% of electricity consumption (Ibid, 133). All along the stages, dangerous waste and effluents - often associated with acids, bases, sodium cyanides, xanthates and ammonium nitrates - are generated (Ibid, 17).

Some examples of rare metals (Wouters 2021, 8):
Copper is a very good conductor of heat and electricity, fundamental for ICT and renewable energies.
Nickel, used in stainless steel production, brings solidity and resistance to corrosion. Thanks to its high energy density, nickel is essential to batteries.
Platinum is a good electricity conductor and resistant to heat and corrosion. Its properties make it an important element of digital applications, including for fast-acting and energy efficient digital memories.
Rare earths represent a group of 17 metals difficult to extract. Four of them - neodymium, dysprosium, praseodymium and terbium - are highly popular. Used for the production of super-strong permanent magnets, they reduce the weight and the size of digital devices such as hard disks. The demand could increase tenfold by 2050 (European Commission 2020a, 6).
Indium, used in thin film production, combines electricity conductivity and optical transparency, appropriate to flat and touch screens.

A growing demand

The demand for ICT is constantly growing. For instance, in 2017, 1,5 billion smartphones were sold in the world, ten times more than in 2009 (Saint-Aubin 2019, 12). Nowadays, smartphone production requires about 9 000 tons of cobalt per year, 10% of the global annual production (The Shift Project 2019a, 31).

This huge and increasing demand of many metals for ICT is not sustainable, as mining has considerable environmental costs. This puts intra and intergenerational equity[5] at stake (reserves are limited and non-renewable), and highlights the rising pressure on ecosystems to get these precious rare metals. For instance, according to the US Bureau of Mines and some private consultancy companies, nickel, manganese, copper and cobalt reserves are going to disappear[6] in the coming decades (Saint-Aubin 2019, 6). The European Commission has also established a follow-up of critical raw materials, according to economic importance and supply risk. In the 2020 list, there were 30 elements, including many necessary for ICT[7].

Environmental impacts of extraction and processing of metals

The mass of materials moved or consumed for the production of electrical appliances with a high electronic component (computers, screens, smartphones) is much greater than the mass of final products: from 50 to 350 times (ADEME 2018, 23). Therefore, extraction of rare-earth metals requires huge ore deposits, energy, and water.

Extraction and metals' processing are dangerous for human health and a threat for the environment through GHG emissions, air pollution (dust and gases), water consumption and pollution, eutrophication, soil pollution and erosion, and deforestation.

For example, to purify a ton of rare earths, at least 200 m^3 of water are required (Pitron 2018, 44). An average gold mine consumes annually as much water as 80 000 French citizens (Systex 2021, 20). Effluents released in the surroundings are rarely addressed, often containing metals and metalloids[8], highly ecotoxic for centuries or even millennia (Ibid, 17).

To produce a 140 grams smartphone, 700 MJ[9] of energy is needed whereas 85 GJ[10] are used to produce a 1400 kg fuel car (ADEME 2013 in The Shift Project 2019a, 29). In the production phase, a smartphone requires almost 100 times more energy per gram than a car (5 MJ/g compared to 0.06 MJ/g). That great amount of energy often comes from fossil fuel combustion. The biggest rare metals producers[11] still don't have a low carbon electrical mix[12].

In the areas surrounding mines, terrestrial and aquatic ecosystems are temporarily or sometimes permanently affected by chemicals and metal pollutants, as well as land and water use, leading to biodiversity loss and toxic effects on human health. On a broader scale, mining contributes directly to climate change and acidification, being responsible for between 4 and 7% of global GHG emissions (Delevingne et al. in Systex 2021, 29), and indirectly through carbon sink destruction.

According to the OECD (2019, 182), the total environmental impact of extracting and processing metals is projected to more than double, and in some cases even quadruple, by 2060, mostly driven by the increase in the scale of materials use.

5 Core principle of sustainable development theorised by the Brundtland commission in 1987 ("Our Common Future").
6 Even if metals deposits are still to be discovered, their difficult accessibility and rentability (low mineral density, social and environmental norms) will lead to shortages.
7 See the final report: European Commission. 2020b. "Study on the EU's list of critical raw materials (2020)".
8 Such as arsenic, antimony, lead, mercury, cadmium and hexavalent chromium (Briffa et al. 2020 in Systex 2021, 16).
9 One million (106) joules.
10 One billion (109) joules.
11 China, Russia, United States, Brasil, South Africa, Democratic Republic of Congo (Saint-Aubin 2019, 16).
12 See on Global Petrol Prices: https://www.globalpetrolprices.com/energy_mix.php?countryId=48

Efficiency improvements in extraction and processing may be happening (less polluting processes and transition towards renewables in electricity production), but environmental impacts will continue to worsen. The growing demand for metals and the lowering concentration of ores in deposits will outperform technological improvements (Geldron 2017, 15 ; Systex 2021, 50).

Picture 3 (Systex 2021, 26): Palabora copper mine, South Africa. On the left, illustration of the quantity of metal produced until 2007 (© Dillon Marsh). On the right, satellite view of the mine and illustration of the surface needed for mining waste and infrastructures (© Google 2021).

Waste and after-mine

Alongside extraction and processing impacts, mining generates a great amount of waste that has environmental consequences. There are two kinds of waste: tailings[13] and waste rocks[14]. A part of both may be used to fill the deposits after mining, whereas the rest is stored at the surface next to the mining site. Because of metal residues, that waste is toxic for water resources through leaching and dam ruptures (Wouters 2021, 18). Picture 3 compares the quantity of metal produced to the quantity of waste generated and the land surface used.

The World Bank (2019, 4) predicts an increase in the number and size of mining sites in the coming decades, leading inevitably to an increasing amount of waste and land use. Environmental impacts will increase, foremost the negative impact on ecological sensitive areas. Sonter and al. (2020 in Systex 2021, 54), find that, today, mining affects 50 million km^2 of land. 8% are linked to protected areas, 7% are key areas for biodiversity and 16% coincide with natural reserves.

Finally, the after-mine phase still requires appropriate and adequate management methods for the closing down of the mining site (safety), and follow-up in the long term (restoration), in order to mitigate the risks and impacts (Systex 2021, 135).

13 Waste material that remains after processing ore.

14 Rock that is removed in the mining process to provide access to the ore.

Use phase, overall impact and innovation traps

Once produced, ICTs continue to have an impact in their use phase, especially for data flows. To make them run and display data across the web, electricity and data centres[15] are required. Therefore, GHG emissions and air pollution are the biggest environmental impacts in the use phase. Indeed, the supposed environmental improvements of ICTs (energy savings) are outperformed by side and rebound effects.

Environmental impacts in the use phase

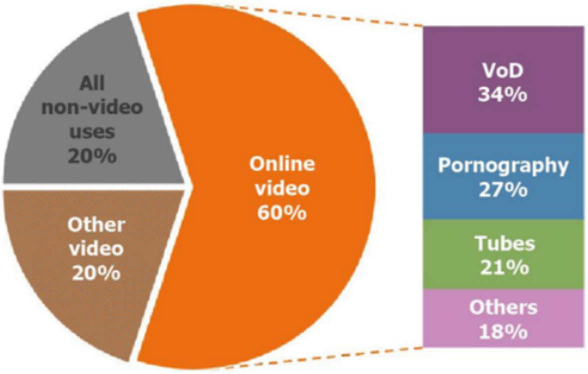
Since 2008, Orange mobile data traffic has been multiplied by 20 (Saint-Aubin 2019, 12). Demand for computing services increased by 550% between 2010 and 2018 (IPCC 2022, TS-132). The increasing use of digital devices, especially for watching video, leads to an increasing demand for electricity, therefore to GHG emissions and air pollution[16]. Data flows are mostly considered due to the fact that they represent the majority of the negative environmental impacts associated with the use phase (The Shift Project 2019b).

The energy impact of watching a video on a smartphone is about 1500 times higher than the electric consumption of the smartphone itself (The Shift Project 2019a, 33). As illustrated in picture 4, online video is responsible for

15 Physical infrastructures generating warmth. To cool them, a high electricity consumption is needed.

16 The global electrical mix is based by 70% on fossil fuels combustion (Global Petrol Prices).

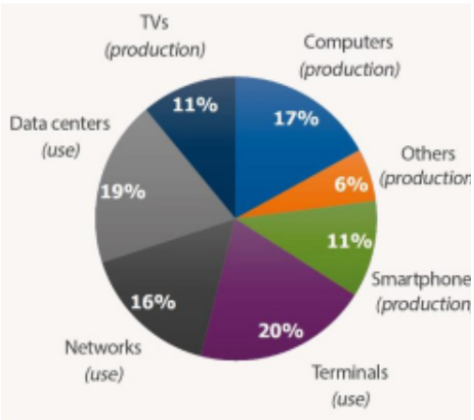
60% of global data flows and more than 300 million tons of CO_2 per year (Ibid 2019b). It represents 20% of the carbon footprint of digitalisation, that is to say 1% of global GHG emissions.



Picture 4: Distribution of online data flows between different uses of digital technologies and of online video in 2018 in the world (The Shift Project 2019b)

Carbon footprint of digitalisation

Along with other environmental impacts previously outlined, digitalisation has a considerable carbon footprint, shared between the production and use phases, as illustrated in picture 5.



Picture 5: Distribution of energy consumption per digital workstation for production (45%) and use (55%) in 2017 (The Shift Project 2019b)

As predicted by the Shift Project (2019a), digitalisation was responsible for 4% of global GHG emissions in 2020. This carbon footprint is constantly increasing, as energy consumption for ICTs is growing by around 9% per year (Ibid). Reasons for this are the growth of smartphone use, the proliferation of daily-life peripheral devices, the rise of the Internet of Things, and the explosion of data flows (Ibid, 20).

Innovation traps

As stated earlier, ICT solutions are currently applied in development strategies to improve human well-being and, in particular, obtain environmental improvements through reduction in inputs (natural resources and energy) intensity per unit of good or service. However, innovations do not always respond to expectations. It is particularly the case for digitalisation, as explained by the IPCC (2022, TS-102): "While digitalisation through specific new products and applications holds potential for improvement in service-level efficiencies, without public policies and regulations, it also has the potential to increase consumption and energy use".

Because of miniaturisation of digital devices and lack of visibility of infrastructures used, direct and indirect impacts are underestimated. For example, the notion of "cloud" leads to thinking of a naturalistic environment in which data is stored and remains out of the vision of the end-user. Of course, "the cloud" is simply a less-than-natural data centre.

Digitalisation can not only involve trade-offs across different environmental matters (e.g. energy efficiency and water pollution), but also lead to a "rebound effect"[17]. Indeed, some of the gains in climate change mitigation can be reduced or counterbalanced by growth in demand for goods and services due to the use of digital devices (IPCC 2022, SPM-13).

For instance, the European Environment Agency (2021) found that the energy efficiency of end-use sectors improved by 30% in the EU-28 countries over the period 1990-2016. However, half of the efficiency gains achieved through technological innovation in the household sector were offset by the increasing number of electrical appliances and by larger homes.

Innovations and technological improvements do not always lower overall natural resources consumption. The more markets are internationally integrated, the more environmental impacts of technological innovations are difficult to predict (Lambin 2015, 82).

End-of-life

To complete the life cycle assessment of digitalisation, a focus has to turn to the end of life of digital devices. For instance, the lifetime of a smartphone is around two years (ADEME 2020). Considering the increasing number of users and devices produced per year, end-of-life is a growing issue for pollution and metals reserves[18].

Outcome of electronic waste and recycling

Once digital devices are considered out of use, they are supposed to be collected by recycling centres. Such waste infrastructures have to exist and be managed adequately in order to avoid wild dumps leading to toxic pollution

17 The rebound effect can be direct: the eco-efficiency of new technologies lowers the cost of a resource or a product, which in turn stimulates its consumption and use. The rebound effect can also be indirect: the eco-efficiency contributes to a global economic growth leading, at a larger scale, to an increasing consumption of other goods and services that require resources (Lambin 2015, 76).

18 At least at the current low rate of CRM recovery from end-of-life ICT products.

of ecosystems and water resources. Components[19] of ICT are toxic and can bio-accumulate and persist in the environment (Flipo and al. 2013). However, sometimes waste infrastructures are not sufficient enough to deal with digital waste. Environmental impacts can be widely distributed geographically if digital waste are traded internationally[20] and if impacts flow across countries (OECD 2019, 184).

To avoid pollution of the environment and waste of critical raw materials, recycling is the solution commonly foreseen[21]. However, less than 40% of electronic waste is recycled in the EU (European Commission 2020c, 8). Recycling centres are not commonly used by ICT owners and still not adequately managed. In the EU, about 50% of some metals, such as iron, zinc and platinum are recycled (European Commission 2020a, 11), and only 65% of copper contained in waste enters the recycling path (Wouters 2021, 11). Moreover, the contribution of the secondary production of rare metals is still negligible. For example, less than 1% of rare earths is recycled in the EU (Ibid, 11) and recycled lithium will only cover 9% of the required lithium for the lithium-ion batteries market in 2025 (Saint-Aubin 2019, 15).

Along with high labour costs for secondary production technologies, technical limits are the most important brakes for recycling. The complexity of metal assembly, product conception, and technology required hinder an

19 Metals, metalloids and POPs (persistent organic pollutants) such as mercury, lead, cadmium, chrome, PBB (polybrominated biphenyl) and PBDEs (polybrominated diphenyl ethers).

20 Usually illegally from the United States and Europe to developing countries. As the latters are less equipped than senders, the risk of pollution is higher.

21 Reuse and repair solutions are more and more common in Europe thanks to the Circular Economy Action Plan https://ec.europa.eu/environment/pdf/circular-economy/new_circular_economy_action_plan.pdf

easy processing of end-of-use devices (Saint-Aubin 2019, 15). While basic materials are easy to recycle, it is more difficult for minerals that have been heavily transformed (Geldron 2017, 9). Besides, recycling is not fully efficient, leading to material losses.

Solutions to lower environmental impacts of digitalisation

Digitalisation can be part of the environmental transition. To reduce environmental externalities, some solutions exist.

Improving recycling and circular economy

Even if recycling is not sufficient to tackle the need for metals extraction[22], great gains could be achieved and lower the environmental impacts of digitalisation. Indeed, the per-kg impacts of secondary materials are estimated to be an order of magnitude lower than those of primary materials (OECD 2019, 16).
Public investment and research in recycling could bring innovations that help to surpass current technical limits. New techniques are needed to separate mixed metals, to recycle directly these alloys and to get back the small quantities of rare metals contained in end-of-use devices (Wouters 2021, 11). Besides, recycling is projected to gradually become more competitive compared to the extraction of primary materials (OECD 2019, 16).

More broadly, the circular economy has to be implemented on a large scale, as its principles could help to reduce the need for new devices. These include responsible consumption[23], ecodesign, reuse, repair, recycling and sustainable supply. Thanks to its circular economy strategy[24] and its international action (through the European Green Deal Diplomacy and the Circular Economy missions), the EU could foster the circular principles implementation in the world, as European norms are globally adopted by producers (Wouters 2021, 22).

"Sustainable mining"

As the production phase - in particular the metals extraction and processing ones - has the greatest environmental impacts, measures could be taken to "green" mining processes. Even if industrial mines have unavoidable externalities (Systex 2021, 27), some improvements could be achieved to reduce them.

While relocating mining in Europe and regaining supply autonomy, EU member states could lead the way to more sustainable mining thanks to EU environmental

22 With a growing demand, recycling will not fulfil more than 20% of the supplies (Geldron 2017).

23 In France, there are 99 electric and electronic devices per home. The general public has to be aware of the need for more sobriety and the myth of "high-tech" has to be broken to avoid mass consumption while owned devices still work (Saint-Aubin 2019, 25).

24 See in particular the "digital product passport" in the proposal for a regulation establishing a framework for setting ecodesign requirements for sustainable products (European Commission 2022).

regulations, as metals extraction has to comply, in particular, with the Habitats[25], Birds[26], Water Framework[27] and Extractive Waste[28] European directives (Wouters 2021, 18). On the other hand, relocating mining in Europe would make Europeans face the consequences of their externalities, and maybe limit their acceptability of them.

Regarding mining in sea floors, as currently under study by some countries, it is not a solution. It could annihilate wild species before discovering them, and destroy marine entire ecosystems and sediments, the greatest carbon storage on Earth (Ibid, 20).

Life-cycle assessment

To avoid a silo approach where one environmental problem is substituted by another, development strategies should look at the full range of environmental consequences (OECD 2019, 185). As shown in this article, a Life Cycle Assessment (LCA) helps to assess direct and indirect environmental consequences, “from cradle to grave”, related to a functional unit (product or service). The method has been developed since the early 1990s and has been standardised to a significant degree (ISO 14040[29] series, UN Life Cycle Initiative[30]) (Ibid, 205). In the current digitalisation strategies, a LCA is required to adopt a systemic perspective, necessary to identify and address trade-offs between resources.

Tackling planned obsolescence

To boost the sales and maximise profits, ICT producers may shorten the lifetime of their products to encourage their replacement (Michel 2019). This planned obsolescence worsens the environmental impacts, especially related to the production phase, and has different types: functional defects (one piece no longer works and the entire product is unusable), planned outage (end of support from a certain date (software)), indirect expiration (smartphone whose battery or charger is no longer available on the market), obsolescence by notification (impossibility of printing because empty cartridge announcement while ink remains), obsolescence by incompatibility (new standards of connectors, cartridges, …), and psychological obsolescence (new products touted as more successful in advertising campaigns) (Raskin 2022). Tackling the planned obsolescence for ICTs is a necessary step to reduce environmental impacts in the production phase. In this light, the European Parliament adopted a resolution in July 2017 “on a longer lifetime for products: benefits for consumers and companies[31]”.

Regulatory action and paradigm shift

Any environmentally sound planning must consider the role of digitalisation in environmental issues. Therefore, regulations on data use online (videos, films, ads…) and on proliferation of connected devices are to be considered (Wouters 2021, 22). For instance, a ban on personal data trade and personalised ads would greatly reduce data processing and energy use, while responding also to safety and freedom issues.

To ensure that digitalisation works as an enabler rather than as a barrier for the environmental transition, an appropriate governance is needed, that is to say a shift from the current paradigm of digitalisation development. To avoid a runaway consumption of digital appliances and to manage the hatching of new technologies[32], some initiatives have been theorised, such as “digital sobriety” from the Shift Project (2019b). It aims at “prioritising the allocation of resources as a function of uses, in order to conform to the planet’s physical boundaries, while preserving the most valuable societal contributions of digital technologies”.

25 https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

26 https://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm

27 https://ec.europa.eu/environment/water/water-framework/index_en.html

28 https://ec.europa.eu/environment/topics/waste-and-recycling/mining-waste_en

29 https://www.iso.org/standard/37456.html

30 https://www.lifecycleinitiative.org/

31 https://www.europarl.europa.eu/doceo/document/A-8-2017-0214_EN.html

32 For example, according to the Haut Conseil pour le Climat (2020), the implementation of the 5G technology could increase the carbon footprint of digitalisation in France by 18% to 45% by 2030.

Conclusion

As new technologies increase productivity and efficiency at work and at home, they are the core of development strategies of main international organisations and national governments. Yet, it appears that ICTs have environmental impacts that mitigate or outperform energy and natural resources savings because of side and rebound effects. In their production and use phase, they are responsible for between 2,1% and 3,9% of GHG emissions and it is going to increase without intervention. To be produced, along with energy consumption, digital products require a great amount of water and chemicals to extract and process their metal constituents. Therefore, ecosystems are strongly affected by the mining activity through water consumption, land use and pollution of the environment. Finally, the defective management of ICTs end-of-life exacerbates and contributes to the environmental consequences.

To make digitalisation part of the solution rather than part of the problem, solutions exist. Recycling and mining practices need to be improved and the circular economy principles globally implemented. Planned obsolescence can also no longer be tolerated. Finally, the policy-making methodology and governance have to be re-examined. Decisions have to be taken according to a systemic perspective, the real societal needs and the planet's physical boundaries.

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The **Rural and Territorial Development Unit** of AEIDL gathers experts who foster communityled innovation by facilitating peer learning, co-creating and transferring of knowledge. The Unit also provides analysis and evaluation of relevant EU policies and advocates for an enhanced support to community local action. It acts as a knowledge

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